E. Novikov

A PLANET OF RIDDLES

ИЗДАТЕЛЬСТВО · МИР ·

Э. НОВИКОВ

ПЛАНЕТА ЗАГАДОК

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A PLANET OF RIDDLES

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The driving power
of cognition is doubt.
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ONWARDS, TO THE TRUTH!

Poor Minister but Great Astronomer

Napoleon put his book aside and paced mincingly up and down the room. Then he rubbed his hands, squinted at the time-darkened portraits of French kings and sat down resolutely at his desk. His pen ran swiftly over the paper. Bonaparte wrote: "... truly regret that the force of circumstances has denied me a scientific career; at least I wish that future generations should not forget, when reading *Celestial Mechanics*, the great esteem in which I held its author ..." The "world's conqueror" considered himself a patron of the sciences. He was a full member of the Mechanics Section of the French Academy. Especially he respected Academician Pierre Laplace. He honoured him imperially, appointed him Minister, made him a Count, decorated him with the Legion of Honour, but the Emperor could not make a high courtier of the great mathematician. Laplace remained true to himself—modest and industrious.

The Emperor's Minister got himself a small house in the midst of a quiet orchard, where he spent all his free time, not resting, but in scientific studies.

Next door was the cottage of his friend, the chemist Berthollet. Without much ado a gateway was made in the fence separating their homes and the friends often called on each other for a quiet chat or an argument about the paths of science. Other callers at Laplace's home were the famous mathematician Lagrange and the no less famous Cuvier. But his most frequent visitors were young scientists. One of these was the rosy-cheeked Swiss Bouvard who but recently could be seen wandering with his whip over the green slopes of the Alps, herding cows. He had gazed at the distant stars and wondered where they came from and what they were. It was his passion for observing the heavenly bodies that had brought him to Laplace. And the latter helped Bouvard to become a member of the French Academy.

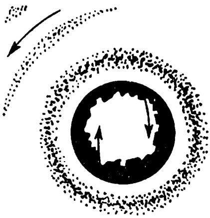
Usually after a morning's work Laplace would allot some time to talks with young promising scientists. He would tell them of his new calculations, discuss his new ideas.

Once—this was in 1796—the ever curious Bouvard asked Laplace what he thought of the origin of the planets, and in particular of our Earth.

Laplace smiled and replied:

"I have been thinking about that for a long time. Since Copernicus we know that the Earth and the planets revolve about the Sun, and, mind you, my dear Bouvard—all in the same direction. Only their orbits are different, some farther away from the day star, others closer to it. Doesn't it seem to you that this universal motion is, perhaps, the key to the secret of the Earth's origin?"

"I don't see," Bouvard shrugged his shoulders. "I really don't understand."



Formation of the Earth according to Laplace.

"Then imagine our Sun, our burning luminary, as a gigantic red-hot gas nebula. It must have been that, I think, in very far-off times, many millions, perhaps thousands of millions, of years ago. Rotating swiftly the nebula gradually spread out and flattened, until it resembled a huge lens. After some time, as a result of its rapid rotation red-hot rings began to tear away from it. Very much like those coming out of your pipe," added Laplace with a smile, noting that Bouvard had gone into a daydream and his pipe was on the point of going out. Bouvard began to puff belatedly. Rings of tobacco smoke floated upwards, large ones at first, then smaller and smaller, and finally a very small one.

Soon the smoke rings broke up into separate bluish clouds. The men followed them silently with their eyes.

"And so, my dear Bouvard," Laplace continued, "I believe that the Earth originated from a similar broken-up solar ring. I have some mathematical calculations that confirm this hypothesis. I'll show them to you later. But just now you will have to excuse me; I must get down to work."

Bouvard rose from his chair with a sigh of regret. He knew his teacher's time was valuable.

But he also knew that very soon his host would invite him again and would not hesitate to share his new ideas with him.

Such was Laplace—kind to his friends, strict to himself. Day in, day out, for 25 years, he wrote his voluminous work *Celestial Mechanics—the Theory of the Movements and Origin of Remote Celestial Bodies*. He put his whole life into it.

Napoleon once said of his Minister:

"A first-rate geometrician, Laplace soon proved quite mediocre as an administrator; his very first steps in this capacity convinced us that we had been mistaken in him. It is remarkable that not a single problem of practical life appeared to Laplace in its true light. He was forever searching for something; his ideas were always a mystery."

To the Emperor he was a poor Minister. But mankind will always remember him as a great mathematician and astronomer, as the man who suggested a daring explanation of the origin of the Earth and the planets.

When Napoleon drew Laplace's attention to the fact that in describing his universal system he had nowhere mentioned God, the scholar replied: "I was in no need of that hypothesis." Indeed, in contrast to many previous theories of the origin of the Earth and the other planets Laplace's theory was not based on clerical dogmas. Later it became known as the Kant-Laplace hypothesis. Scientists found a similar assumption as to the origin of the planets in a very old book. True, this book asserted that the cosmic nebula had formed from cold particles, rather than red-hot gases. The author of the book was unknown at first and only after a thorough investigation was it established that it had been written in 1755 by the German philosopher Immanuel Kant.

But Laplace knew nothing about this book. A grave illness struck him down in spring, 1827. Unconscious, he raved in delirium about what had filled his whole life. So, with his thoughts fixed on the boundless universe, passed away Pierre Simon Laplace.

If Another Star Passed by

Sir James Hopwood Jeans was a physicist interested in the properties of terrestrial gases. Strange properties these are, for gases may be solid or liquid, cold or white-hot.

Like any other Englishman, James Jeans had his habits and traditions. Every evening he would go out for a walk to give his brain a rest before going to bed. But often his daytime thoughts pursued him far into the night. Looking at the yellow street lights blurred in the drizzling fog, he pondered over the movement of gases. Sometimes the rain and fog would give way to clear blue-skied evenings, and then the scholar preferred to gaze up into the night sky and enjoy the starry vault of the sparkling Milky Way.

It may have been on one of these clear evenings that Jeans decided to tackle a problem not quite in his line, to give a new explanation of the Earth's origin.

According to Laplace's hypothesis our planet originated from white-hot gaseous rings. But who knew more about gases than Jeans? A detailed study of the theory of formation of the planets soon revealed that the force of rotation of the Sun was too small to throw gas nebulae out so far into the surrounding space. If this force were large enough to do so, the Sun would long have dispersed into space as a result of its rotation.

According to Laplace, the solar nebula was originally oblate. It could hardly have changed very much since the Earth was born; still astronomers could discover no considerable flattening of the Sun's shape though it was measured time and time again after Laplace. Hence, the great Frenchman had been mistaken. But what could take the place of his theory?

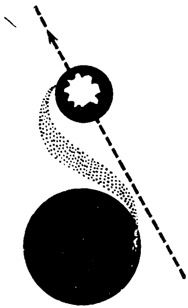
Then James Hopwood Jeans remembered an assertion made by the scientist Buffon. Before Laplace, in 1750, this scholar had suggested that the Earth might have originated from a piece of the Sun torn out as a result of attraction by another celestial body. Buffon called such a body a "comet".

Jeans decided that this was closer to the truth. It seemed quite clear now that the Sun itself could not have created its distant planets. This idea was supported by the new "planetesimal hypothesis" of Chamberlin and Moulton. From America, from Chicago, the meat merchant capital, came this hypothesis in 1905, stating that the planets had been formed from material pulled from the Sun by the tidal force of a passing star.

But what about the Earth's eternal fellow-wanderer, the Moon? Where did it come from? This the hypothesis of Chamberlin and Moulton could not explain. And James Hopwood Jeans got down to the task of refining their hypothesis.

Two very hot bodies would possess the properties of gases and liquids, so he reasoned. If they came close to each other, mutual attraction would cause bulges on their surfaces. If the bodies were of the same size, the bulges would also be the same. But if they were different, the larger body would pull out of its smaller neighbour a stream of hot gases greatly resembling a long sleeve. Under the action of the two revolving stars this "sleeve" would begin to revolve between them. Then, when the "stranger" star flew off into outer space the fiery stream gradually contracted into separate planets. Now the Sun caused bulges on the surfaces of these planets and tore condensed fractions out of them. So was born the Earth's daughter, the Moon. Time passed and the fiery Earth cooled down, becoming more and more like our planet today.

Jeans advanced his "bulge hypothesis" in 1916. In reward the British government appointed him President of the Royal Astronomical Society. Had he not defeated the Kant-Laplace theory which



Formation of the Earth according to Jeans.

for a hundred years had influenced the views of scientists? But Jeans' "bulge hypothesis" existed a much shorter time, only a quarter of a century.

No! The Earth Was Born Cold

"Schmidt!" called the teacher. Otto got up, went to the blackboard, took a piece of chalk and was soon lost in thought. His face was pale and wrinkles showed up at the corners of his mouth. He had just recovered from a serious illness and was now back at school but ...

"What's the matter, Schmidt?" asked the teacher. "Haven't you prepared your lesson?"

"No, Sir."

"Then you get a bad mark. Nothing else I can do. I'm obliged to."

"He has been ill! Don't do that," came voices from all around. "He'll catch up!"

'The mathematics teacher frowned, smiled a little and resumed his stern demeanor. He looked intently over the class and then said to the pupil at the blackboard:

"Sorry. You may go back to your seat."

"No I won't," Otto rejoined. "I'll try to prove the theorem in my own way."

Timidly at first and then more and more boldly Schmidt chalked up numbers and formulas. And with each chalk mark the old mathematician's eyes opened wider and wider. Sarcasm gave way to surprise and then to delight. The seventh-form pupil's future seemed quite definite: his vocation was mathematics.

But why then many years later did Otto Schmidt travel to the distant Pamirs? Why did he take part in the famous Arctic expeditions? Because geography also became his vocation.

Among rocky peaks or cold icebergs everything reminds one of the great, as yet unknown Universe. There, overhead, the stars twinkle like diamonds. From there the boundless Universe is easier to see. And Otto fell time and again to thinking of the close relationship between our planet and the distant heavenly bodies scattered over the sky.

He imagined the Earth as an integral whole with its deep oceans and high mountains, with its warm blossoming gardens and white Arctic cold. His friends would joke about him: "Our Otto thinks in terms of planets, grips the entire globe all at once."

Yes, Academician Schmidt had for a long time thought of the Earth as a planet. But he did so in his own original way. His pondering was not abstract like that of the mathematician Laplace, according to whose theory the planets formed prior to the Sun.

His reasoning was not narrow-minded like that of the physicist Jeans, who assumed that at first there was the Sun and then a passing star created a planetary system around it. Schmidt thoroughly studied the structure of our planet and of the Universe. He was at the same time an illustrious mathematician and an excellent physicist.

On that bright day at the turn of the second half of the century the sun flooded the long corridor of the Leningrad University with sultry light. It was unusually still here. But close by, in the great assembly hall were gathered professors, students, geologists—in a word, all the curious. They not only filled all the seats, but also occupied the long gallery encircling the hall, crowded the aisles, and the most desperate even perched on the window sills. All of them had their eyes fixed on the man standing on the rostrum, a man with a youthfully unruly mop of hair and the imposing beard of an old sage.

The speaker was expounding his new theory of the Earth's origin.

The Earth! This great sphere on which people live, which feeds and clothes them, and gives them life. But how was it born?

For a long time it had been taught that our planet had previously been a fiery liquid body which gradually cooled down. So asserted Laplace and so asserted the Englishman Jeans, who was able to avoid many of the errors of the great Frenchman. But he himself was in error in many respects.

Indeed, to draw a gigantic "sleeve" out of the Sun, the other star must have been close to it. Then what force drove the future Earth so far away? And where is that single star that happened to be passing by?

The English physicist had no answer to these questions.

If Jeans' hypothesis were correct, the fiery stream would have to have escaped from the interior of the Sun where the temperature is millions of degrees; but then the hot gaseous "sleeve" would not have had a chance to break up into separate planets. It would have just scattered, evaporated, as it were, into space.

Besides, interstellar space cannot be regarded as a vacuum containing individual stars and planets. It is filled with innumerable accumulations of cosmic dust, flying and whirling about. Possibly, the particles greatly resemble those that fall sometimes on Earth as meteorites. Are such accumulations hot? No, they are not. They are as cold as ordinary terrestrial rock. In this sense, the German philosopher Kant's assumption was probably more correct.

The Sun and the Earth are moving in the Universe. At times they pass through nebulae. Then a "stellar shower" can be seen in the night sky. Thousands, millions of fragments of the "celestial" stones burn up in the Earth's atmosphere, which is a kind of protective clothing. But previously there was no such atmosphere, and our planet was nothing but a shapeless cloud of gas and dust. The cloud grew and grew as it imbibed gigantic fragments and tiny particles from the interstellar nebula. They fell in a heavy shower on the surface of the future Earth. Like bombs, they exploded, broke apart, yielding their energy, their motive power to the growing planet. Time passed. The bombardment, the transformation of energy from one kind into another, made the future Earth vibrate: erratically at first, like a light boat on a stormy sea, then more and more evenly. And then the planet began to revolve. The forces of rotation flattened it slightly at the poles and compacted it, forcing the heavier particles towards the centre of the gigantic rocky sphere.

So, in the opinion of Academician Otto Schmidt, was born the Earth. Only afterwards did it begin to warm up and its rocks began to melt as a result of the decay of radioactive substances.

Not fiery and gaseous, but cold, rocky, and lifeless, like the peaks of contemporary mountains—such was our warm and cosy planet many thousands of millions of years ago.

Schmidt's hypothesis explained simply the tremendous size of the solar system. An interstellar nebula is boundless. Schmidt's assumption eliminated many obscurities associated with the different rates of rotation of the Sun and the planets, because according to this assumption the planets were not born of the Sun.

But the main thing was that this theory was based for the first time on numerous scientifically confirmed facts. That is why it found many adherents. But...

There Are Still Other Opinions

Have you read the poem by the great dreamer Alexander Pushkin, where he writes:

A pale spot gleaming in the sky,
The moon shone yellow
Through the stormy clouds... *

The Moon is indeed a spot in the sky. Such we see it at night whether it is gloomy and overcast or clear and starry. Such we sometimes see it even in bright daylight. But viewed through a telescope our eternal satellite is an immense sphere with mountains and valleys. Numerous

* Translation by D. Sobolev.

circular depressions can be seen clearly on it. What are they? Traces of fallen meteorites. According to Schmidt the Moon also originated as a cold condensation pelted by a rocky shower of interstellar nebula fragments. But they may be craters of extinct volcanoes much like those on Earth. Some scientists think so.

Academician D. ·Fesenkov, a prominent Soviet astronomer, believes that the Moon and the Earth are of approximately the same age as the Sun, and that the substances composing them were formed from a circumsolar gas-dust nebula, rather than from an interstellar accumulation. The Moon and the Earth are the "children" of a young Sun. Revolving and gradually contracting, it caused eddy condensations around it, which eventually became the planets and their satellites.

The Moon! Its surface is covered with thousands of craters and mountains, large and small. Some of these mountains resemble the dome of a gigantic circus, others are much like the Caucasus or the Pamirs on Earth.

But could falling meteorites have made pits with polygonal edges and projections? Where did the lunar seas, smooth as a football field, come from?

They are probably traces of moonquakes and unparalleled volcanic activity which produced fiery oceans of lava that spread out, perhaps, over hundreds and thousands of kilometres. Among them, like islands, rose the famous ring-shaped mountains.

One may object that no such mountains are known on Earth. But it should not be forgotten that for thousands of millions of years water, air and wind have levelled out, worn down its previous surface. If whole mountain ranges like the Urals are dying, ring-shaped mountains created by such volcanic activity may have vanished entirely.

But again one may object—doesn't the same occur on the Moon's surface? Hardly. Because the moon has no mountain eroders, neither atmosphere nor water. What it was in far-off epochs, such is it mainly at present. It has only turned cold.

And one more question.

It sprang up one night in November, 1958. As is usually the case with astronomers, Professor Nikolai Kozyrev, of Pulkovo Observatory, started his observations late in the night. He was serenely watching through the slit of a spectrograph when suddenly he noticed something unusual on the mountain peak in the middle of the lunar crater *Alphonsus*.

Kozyrev developed the spectrogram. On it he saw a bright band in the spectrum of molecular hydrogen. It was a sign of a volcanic eruption.

"So the Moon is not dead," concluded the scientist.

Later, evolution of gas was detected in another lunar crater, *Aristarchus*. It resembles what is occurring in terrestrial volcanoes.

During a total lunar eclipse the Sun does not illuminate the Earth's natural satellite and its rays do not warm its surface. Now what if we measure the temperature of the supposed craters at such a moment? The observations carried out in 1964 discovered more than 300 "hot spots". But the assumptions remained only assumptions.

In February, 1966 an unusual press conference was held in the Moscow House of Scientists.

Before the eyes of those present stood not hazy smudges of photographs of our planet's satellite made from the Earth, but snaps taken by a photographer right on the Moon's surface. The photographer was the Soviet space station *Luna-9*.

The photographs indeed show a rocky desert. The lunar relief is not coated with a thick layer of dust, as many thought just recently, but is solid volcanic rock. Meteorite bombardment has not loosened its surface to any considerable depth.

Immense craters up to 300 kilometres in diameter are covered with erupted lava. This lava probably also "floods" the waterless seas, most of which are on the Moon's visible hemisphere, as had been known previously from photographs received from other artificial satellites.

All this is so much like our Earth, where there is more dry land in one hemisphere and more ocean water in the other.

Maybe other opinions are closer to the truth than the meteorite hypothesis?

But this evidence does not yet warrant sweeping conclusions. Too many facts are needed to embrace the boundless.

And here are new facts. The content of radioactive elements in lunar rocks is very much the same as in volcanic rocks on Earth. Lunar stone resembles meteorite matter very little. This evidence was given by the *Luna-10* space laboratory.

Just what is this mysterious moon rock or "lunite" as it is called?

At one time Academician A. Vinogradov assumed it to be basaltic rock. Then, nobody on Earth had ever held a lunar stone in his hand, and Vinogradov's surmise was only scientific prediction.

But on July 20, 1969 Armstrong first set foot on the Moon's surface.

Before him lay the *Sea of Serenity*, all gray and crisscrossed with weak rays of outbursts from distant and large craters. Nearby were only hollows resembling shell holes. The part of the Moon's surface near the landing site was covered with a mixture of tiny particles, sand, stone fragments and boulders. The astronauts' footsteps left impressions in the soft porous ground. The Earthman took samples of the ground and picked up lunar stones....

Five days later the *Apollo-11* spaceship delivered 22 kilograms of an unusual freight to our planet. And some time later the crew of the *Apollo-12* brought in 50 kilograms of "lunite" from another point, from the *Ocean of Storms*. Hundreds of experts studied these samples and investigated the properties of the ground. It is not dust and its average density is higher than on Earth. Destruction—erosion—evidently occurs on the Moon. But there it does not involve the action of atmosphere or water, for the Moon has none. But the innumerable pits on its surface are lined with a vitreous mass, and balls of the same mass are also found—evidence of bombardment with small particles. This was a discovery.

Ferns were planted in the non-terrestrial ground, and oh wonder, they thrived better than on Earth. But no signs of life were found in that ground.

Determination of the composition and structure of the lunar stones showed them to resemble those of the ocean bed on Earth. Gray and dark, they are very much like basalt lava. Thus, the Soviet scientist's prediction came true. The lunar samples also included breccia—masses of fragments and sand particles fused under the action of meteorite impacts. Our planet has no such formations. However, the time of "birth" of the lunar stones is close to that of the oldest stones on Earth. Such is "lunite" on the surface. But what is it like in the interior?

The crew of *Apollo-12* left on the Moon a seismograph, to measure moonquakes. Then they dropped their lunar module onto the ground, for it had already served its purpose and was no longer needed. The instruments registered vibrations for 50 minutes, whereas on Earth they would have lasted for not more than 50 seconds. This suggested that the structure of the lunar interior in the zone of the impact resembles a layer cake with alternating compact and loose layers. Thus the celestial relative of our planet apparently has much in common with it but also differs in many respects. Perhaps the Australian investigator S. Taylor was right in calling them "cousins, not sisters".

Scientists now have new riddles to solve. They still find it difficult to answer even the main question: "How were the planet of men and its inevitable satellite, the Moon, born?" Nor is there anything very strange about this. Each year science brings mankind more and more knowledge, often contradictory, and not infrequently refuting what has long been known and asserting what would seem to be unbelievable.

Laplace and Jeans thought our planet was born of a fiery eddy.

Today many scientists say:

"That is not so. From the first day of its origin the Earth was cold. Only afterwards did it warm up under the action of the radioactive fuel buried in its interior. Then it gradually began to cool down again.

Our planet came from an immense cloud of gas and dust. Whether it was in interstellar accumulation or a circumsolar nebula remains to be established.

ITS SHAPE WAS DETERMINED AT A WRITING DESK, ITS SIZE MEASURED OUTDOORS AND ITS WEIGHT INDOORS

The Peripatetic School

"And so, gentlemen, let us begin our lecture." As he said this Aristotle stepped out from behind the rostrum and hurried out into the street, followed by his pupils. Soon they were walking up and down green alleys. The morning sun sprayed a yellow shower among the leaves of the olive trees. Now and then a hot beam would fall on the youths' tanned faces or light up the silver-gray beard of their teacher. The mischievous luminary disturbed the philosopher, making him squint. But it could not make him return to the stifling classroom of the Lyceum (one of the higher schools of Athens). Aristotle was accustomed to delivering his lectures while walking in the fresh air. For this reason his pupils gave him the nickname Peripatetic (from the Greek word for "walk about") and his unusual group was named the Peripatetic school. On that day "those walking about" were having a lesson on the Earth s shape.

"As you know, my friends," said the philosopher, pacing the stony path, "not very long ago the Earth was thought to be a flat island, surrounded by the river Oceanos. But even before that Thales of Miletus thought differently. He believed that Oceanos was beneath the Earth.

"Now why, do you think?" asked Aristotle and fingered the diamond brooch fastening his splendid tunic at the shoulder. Both diamond and tunic were presents from his first pupil, Alexander the Great.

"Well, what do you think? Why," he repeated. The youths knew not what to answer. Their teacher frowned: "Of course, like Alexander the Great, these children of rich men will never be real thinkers. Their minds are fixed more on military campaigns. There are none worthy of note among them." And breaking the silence Aristotle himself began to explain. "It should be quite clear to you: Thales wanted to account for earthquakes that way. He considered them to be caused by storms of the underground Oceanos. His younger friend Anaximander thought the Earth was chequer-shaped. And the venerable sage Xenophanes even compared the Earth with an immense stump. This stump had roots reaching down into infinity and so supporting the body of the Earth in space. Anaximenes supposed the Earth to resemble a large plant lying flat. Even my esteemed teacher Plato declared it to be cubic in shape."

With this Aristotle finished his lecture.

"And now you may have a rest. Afterwards I will tell you what I think of the Earth's shape."

The pupils ran off noisily to the Lyceum sports grounds, and the philosopher remained alone. He sat down on a bench of snow-white marble and his mind went back to the past.

How recently, had he also been young, and like those youths also loved sports and merriment, but he had loved work still more. Plato said of him: "Others need the spur. Aristotle needs a bridle."

Yes, he constantly had to restrain his thoughts, to keep them from running away with him. He must get an understanding of the teachings of the great mathematician Pythagoras, and finish his own book *Analitics* on the science of correct thinking, logic, and he also had to look into the affairs of the Lyceum. He had to find time for all this.

Aristotle raised his head and glanced at the sun dial. It seemed to him that the shadow of the stone column, like a rotating hand, moved faster and faster along the bronze circle with the divisions of inexorable time carved on it.

"Yes, time flies. It never waits..."

Aristotle got up hastily and clapped his hands. His pupils came up one by one. And now they again paced the paths of the Lyceum park, listening to their great teacher's new theory of the Earth.

"Imagine the Earth flat," he explained. "In rising above it the Sun would simultaneously light up both distant and nearby lands, the whole Earth, as a matter of fact. But we know that this is not so. Morning comes to different lands at different times. It does not coincide with our Athenian morning. But what if we suppose the Earth's surface to be convex? Then everything is much easier to explain. The day star rises higher and higher. Its light penetrates gradually further and further. And the night's darkness retreats like a defeated enemy from the battlefield. And here is some more evidence: it lies in the night sky, in the stars. If we go some distance north or south, does not the sky become different? Do not the positions of the stars overhead change? But it is best of all to observe not the stars but the Moon at night. Have a look when our Earth takes up a position between the Sun and the full Moon. Then the Earth throws a shadow into surrounding space.

"Look around you," said the teacher. "See the cool shadows of the olive trees. They reflect the shapes of the trees. And have you not seen how the golden disc of the Moon is darkened by the Earth's shadow? That shadow is round..."

...Yes, the wise philosopher was right. Aristotle was one of the first to notice that our planet is a sphere. He came to this conclusion through original reasoning almost 23 centuries ago.

Today we are no longer in need of such reasoning, for spacemen have seen with their own eyes that the Earth is round.

One morning the heralds spread the news through the town: King Ptolemy III Evergetes had appointed Eratosthenes of Cyrene librarian of the great library of Alexandria. From that day on, instead of wandering in unknown parts, the scholar would have to sit in the twilight of stony rooms, guarding valuable manuscripts.

Some people might have found it dull to be a librarian, but Eratosthenes was not despondent. He decided to read everything he could find on travels and on discoveries of the Earth's secrets. Then he would write a big scientific book containing all the geographical knowledge of those times.

This work, which Eratosthenes called *Geographica*, took up a great deal of time. Still sometimes the librarian would leave his quiet office and go out into the sunny streets of the city. He would make his way to the Alexandrian bazaar where simple folk argued and bargained. There camels, wearied after their long journey, rested nearby, chewing their cud indifferently and dripping hot saliva into the dust.

Such a life, all open to the public eye, was to Eratosthenes' liking. The royal librarian was wont to sit down somewhere in the shade of a shop wall and start a conversation with the visiting merchants.

On this occasion, too, one of them was telling him, while mopping his sweaty face with a coloured handkerchief:

"Our town of Syene is the hottest place ever. They say there is no other such place on the sacred Earth. Here when we sit in the shade it seems a bit cooler. But in Syene there is a day once a year when there is no shade to be found."

Eratosthenes was surprised.

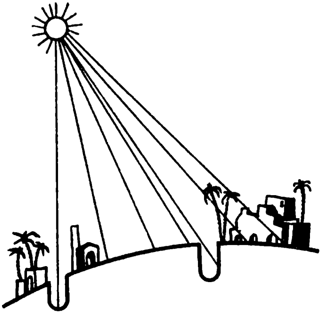
"Wait, I don't quite understand what you mean. A shadow may grow longer or shorter, but I've never seen there to be none at all."

"Nevertheless, in our Syene, on June 22 at mid-day you will find no shade at all," retorted the merchant stubbornly. "Oh yes, on that day you can see the bottom of the deepest and narrowest well. Believe me."

The stranger's story made Eratosthenes fall to thinking. Even on the quiet streets of the town along which he walked back home, somebody seemed to whisper continuously: "Oh, yes, at mid-day you can see the bottom of the deepest and narrowest wells there."

"Why?" the scientist asked himself. "Maybe because the Sun's rays there fall perpendicularly?" And then retorted: "But no such thing ever happens in Alexandria."

These thoughts gave the librarian no rest even in his cool office. He sought out and reread manuscript after manuscript, trying to understand: "How can such a thing be?" It was the works of the great Aristotle that suggested the answer. That wise philosopher asserted that the sun illuminates different parts of the Earth's surface differently and that its rays have different angles of incidence because the Earth is a sphere; hence, the length of the sun's shade cannot be the same everywhere at the same time.



Eratosthenes' method of measuring the size of the Earth.

Now what if we turn to the Sun for help in measuring the size of the globe?

That is just what the Alexandrian librarian decided to do. He had no intention of making a long journey to measure the distance from one town to another step by step. His idea was to measure the Earth without leaving the little courtyard of the Alexandrian library. He constructed a special scatha or bowl, resembling a greatly enlarged half nutshell. At the centre of the bowl he fixed a column. Then he set up his invention in the library courtyard and waited for the longest day in the year.

On June 22 the sun arose in the sky above Alexandria. At that moment the scientist measured the length of the shadow the column threw on to the bottom of the bowl. He found it to be one-fiftieth of the scatha circumference. At that same moment there was no shade at all at Syene (vicinity of the modern Aswân): there the sunbeams fell vertically. The distance between the two cities was 5,000 stadia (the *stadium* was a Greek unit of length) or 800 kilometres. Such would be the length of one of 50 equal arcs constituting the complete circumference of the Earth. From this Eratosthenes calculated the entire circumference to be 800× ×50=40,000 kilometres. Then by a simple calculation he found the radius of the globe to be equal to 6,370 kilometres.

Since then investigators have measured the Earth's surface many times, but their results always coincide in the main with the figures derived in ancient times by Eratosthenes. These figures have also been confirmed by the space laboratories of artificial Earth satellites.

Thus, the Alexandrian librarian measured the earth correctly almost 2,200 years ago.

On the Shore of the Ocean of Truths

You have all heard of Westminster Abbey which stands in a well-to-do district of London. It has stood there for almost 900 years now. How many English kings have ceremoniously come out of this ancient building to begin their rule of the British empire. Afterwards they returned, but now to the sounds of funeral music. Here were they crowned and here were they buried.

Though Isaac Newton was no king, he is also buried at Westminster Abbey. The words engraved on his tombstone read:

"Here lies Sir Isaac Newton, who by the almost divine force of his mind first explained with the aid of his mathematical methods the movement and shapes of the planets..."

Numerous were the merits of Sir Isaac Newton, and many of them are mentioned on his tombstone. What is not mentioned, however, is that the great scientist lived almost all his life in poverty, and started not in the capital, but at Woolsthorpe, a small English village, near Grantham in Lincolnshire.

A strange boy he was, whether because he grew up without his father, who died in 1642, a few months before his son was born, or because he became engrossed too early in his inventions and ideas. His mother dreamed that her son would take up farming and put the family's little estate in order. Indeed, young Newton would leave the house more and more often to go out into the garden. Following him with her eyes as he left his mother would sigh with relief: "My son will be a good farmer, and will make our fortune."

Once a relative from the big city came to visit them. Isaac was not at home. The relative went out to the fields to see his industrious nephew.

And he saw Isaac sitting just outside the fence, absorbed in a complicated book on geometry. Afterwards his uncle came many times unnoticed to the fields and every time he saw his nephew at his books.

"He will never be a real farmer," he told Isaac's mother. "Better send him off to study. I'll help you."

And so the boy went off to study. He graduated at Cambridge and became a scientist. The young investigator was interested in everything; he carried out experiments with light, tried to account scientifically for the phenomenon of rainbows, and finally took up a stand against the famous Academy of Science. For what cause? Only in the cause of the truth.

In 1672 the Frenchman John Richer accidentally noticed that a pendulum beat slower at the equator than it did in Paris and was obliged to correct its motion by shortening the pendulum. Then Richer reported on these phenomena to the Academy of Science. The academicians did not take much time to think. They resolved: "It is due to the tropical heat which lengthens the pendulum."

It was then that Newton "tactlessly" declared: "Heat is not the cause. It could have been, were the temperature at the equator 200 degrees higher than in Paris. The main reason is the oblateness of the Earth, the force of gravitation."

"Well, that's the limit!" exclaimed the esteemed scientists.

Incidentally, Newton, who had discovered the action of these forces, was no less agitated than they were. He could not even finish his calculations to derive the formula of the law of universal gravitation, and asked a more coolheaded friend of his to do it for him.

Professor Isaac Newton agitated? The students at Cambridge could not believe it. They were accustomed to the dull lectures of the strict mathematician, to his unruffled composure. But their teacher was at the same time one of the greatest dreamers. It was Newton's imagination, reinforced by profound knowledge that helped him to determine the shape of the Earth in an unusual way.

If two holes were bored in the Earth down to its centre, he reasoned, one from the North Pole and the other from the equator, and filled with water, how would the liquid behave? Would it run out? No! Would it stop at equal levels? No, again.

In the vertical well, dug from the north, the water is under the action of gravity, which pulls it to the Earth's centre. But in the horizontal well there are two forces acting: one of them also draws the water towards the Earth's centre, pressing it against the bottom of the immense well, but the other tends to throw it out of the well. This force, due to the rotation of the globe, is called centrifugal. It pulls the water outwards from the Earth's centre. Thus, the net force in the horizontal well is smaller, and hence, to balance the liquid in the two channels part of it must pass from the vertical to the horizontal one.

Newton figured out where equilibrium would occur, and found that it is reached when the level in the horizontal well is 1/230 higher.

Therefore, for water not to flow out of the hole bored through the equator, the rotating Earth must be a slightly flattened sphere. Sir Isaac's premises were quite extraordinary, for the Earth cannot be bored through like a pumpkin, nor can water be poured into it.

Still, Newton was right. His conclusions have been confirmed by the calculations of many researchers, including those of Soviet scientists. The Earth was found to be shaped more like a tangerine than a sphere. According to the latest information brought in recently by artificial satellites, the Earth is even slightly pear-shaped.

It has been found that the North Pole is 30 metres higher than the South Pole. How little for the giant Earth! Still, even this trifle may be evidence of the enormous internal stresses experienced by the body of our planet.

Satellite measurements have made it possible to determine the Earth's oblateness more exactly. It equals 1/298.4, meaning that the equatorial diameter is 42.77 kilometres greater than the polar diameter.

But even these new figures concerning the oblateness of the globe show primarily how correct were the theoretical calculations made several centuries ago by Isaac Newton. Thus, the dull professor appears actually to have been quite a different man. He was a great dreamer who succeeded, using incredible assumptions, in finding the most correct solution for his time concerning the Earth's shape.

"I do not know what people think of me," said the scholar, "but to myself I seem like a child playing on the seashore, full of delight when he comes across a smooth stone or a pretty, not quite common shell, whereas an immeasurable ocean of truths lies uninvestigated before him."

Yes, an ocean of truths! It still held many secrets. For instance, who could give the correct weight of the planet?

A Six Followed by 21 Zeros

He walked very slowly around the mountain, measured it, then went back home and made some calculations. Then he returned to the mountain and estimated its breadth, height, and volume again and again.

Every time the local inhabitants asked him: "Why are you measuring this lone mountain in the field?" He replied: "I am going to weigh the Earth." "He's probably kidding," thought the country people. "Maybe he's a crank. All the Scotch are a bit rum. They eat oats and their men wear skirts, and what not." And so was this one—wouldn't tell them what he wanted from that mountain.

But the country folk were mistaken. The Scotchman Hutton was not fooling them. He really intended to "weigh" our planet with the aid of a small mountain, an ordinary plumb bob, and the famous Law of Newton. This law states that the force of attraction between two bodies depends on the distance between them. The smaller the distance between two objects, the stronger they attract each other. The two bodies were a mountain and a small weight suspended at the end of a string. They should attract each other. The mountain could not be displaced because it was stationary, but the plumb bob could easily be deflected towards it like a pendulum.

And that is why Hutton walked around the mountain, measuring the deflection of the little weight towards it. Then he began to calculate the weight of the Earth. To do so he had to know the weight not only of his plumb bob, but of the mountain as well. And so he measured its volume, and found the average weight of a unit of volume of its constituent rocks. Still, his calculations were too crude.

However, Hutton hardly thought anybody could do better. Only if they invented a balance to weigh the mountain with, perhaps? But that seemed quite incredible.

However, only twenty years later, in 1797, such a balance was invented. It was not a complex or bulky device but something very simple and small. Its working principle was well known even to Hutton. Anybody could have thought of it. But could just anybody have thought of "weighing" our huge planet on a toy swing?

This task was undertaken by an inhabitant of foggy London. Gloomy and unsociable, Henry Cavendish rarely spoke to anyone. He did not care about anyone's opinion. Nor did he make much display of his own curiosity. All alone he went over his simple apparatus again and again before he ventured to start his final experiments. No wonder—he was going to "weigh" the planet!

But at last came the time for weighing.

"First we fix a rod," reasoned the scientist, "so that it is balanced like the beam of a pair of scales, and rotates only in a horizontal plane.

"And so we begin." He took a light rod from the table and tied it carefully to a plumbline. Then he fastened two identical lead balls to the ends of the rod. After this he stepped aside and observed the tiny balls for a very long time. Nothing special happened. They just remained stationary. But that was what the investigator wanted, since it meant that the torsion balance was at equilibrium.

There were two large lead spheres in the next room. Cavendish brought them gradually closer to either side of the balance. Now he had to be very careful not to miss the main item. He kept very still watching the balance intensely. The distance between the large and small spheres decreased from 30 centimetres to 25, then to 20... The rod began to move. The small spheres were attracted to the large one, twisting the plumbline. Henry Cavendish repeated the experiment again and again, each time calculating the force of attraction between the tiny and giant spheres from the angle of turn of the rod. Then he calculated how much this force was smaller than the gravity of the Earth. He determined how many times the density of the Earth was smaller than the density of lead. And finally he was able to calculate the mass of the Earth.

The figure he obtained was: 6,000,000,000, 000,000,000,000 tons! A six followed by 21 zeros.

"Weighing" the Earth brought up new puzzles. The planet turned out to be almost twice as heavy as a stone sphere of the same size.

IT REVOLVES AND VIBRATES

A Ball on a Wire

"Paper, paper!" cried the newspaper boy. "Sensational discovery! Anybody can see the Earth's rotation!"

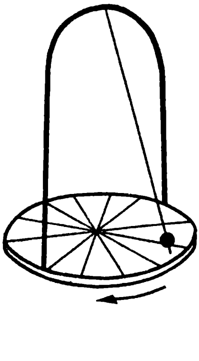
So, on April 21, 1851 was the world informed of the clever experiment of the French physicist Jean Foucault.

A month later a Moscow newspaper carried Professor Zernov's announcement that soon an instrument would be set up at the University by which anybody could "by witnessing with his own eyes convince himself of a truth that has heretofore been accepted by the majority on the authority of learned astronomers."

A place for the experiment was found near the splendid staircase in the side hall. A copper sphere, with a pointed stylus attached to its bottom and weighing 26.6 kilograms, was suspended on a steel wire 17 metres long and tied to a support with a cord to make it hang motionless and strictly vertical.

A square frame was laid on the floor under it and paper was glued on top of it to form a concave surface. Circles were drawn on this surface and degrees marked on it. Then the cord was burned and the pendulum was set in motion exactly on the zero line. Only 5 minutes later everybody could see that the line of swing of the pendulum had moved slightly. As usual, there were those who doubted. What if it were simply a trick—someone up there slightly rotating the wire.

Another instrument was made to convince the sceptical. It was also a wire with a sphere at-



Foucault's pendulum.

tached to it. But this instrument was a small one and had a wooden disc fixed to the top of the wire.

With the instrument at rest the doubters were asked to rotate the disc. And, of course, this made the wire rotate also together with the ball. The doubt seemed confirmed.

But then the attendant made the pendulum swing and when they were again asked to rotate the disc, what was their surprise when now the pendulum kept swinging along the same line, along its crossbeam.

"Rotating the wire cannot change the direction of swing of the pendulum," the attendant explained. "That is a well established law of physics. There can be no question of any tricks.

"You have noticed that the lines of swing of the pendulum are deflected, as it were, to the left, towards the west. This is a vivid proof of the fact that the Earth moves around its axis in an easterly direction."

Later this experiment was repeated many times in different cities. A plumbline, this time 98 metres long, was suspended in St. Isaac cathedral in Leningrad. The northern Palmyra is nearer to the pole than Paris, and therefore the deflection of the plane of swing of the pendulum is greater and easier to notice than where Foucault first suspended his pendulum from the domed ceiling of the Pantheon in Paris.

Two Hundred Years Ago and Today

At the beginning of our century a meeting of a scientific society of naturalists in Switzerland passed a resolution to publish the works of the great mathematician Leonhard Euler. But though they started in 1910 they were able to put out only half of his works in the following 50 years.

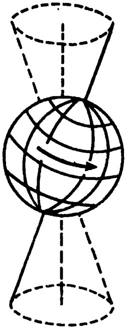
They probably went about it very slowly, you may say. No, it was not that. Somebody once figured out that if a person were to rewrite the scientist's works eight hours a day it would take him fifty years of his life to finish them all!

Very great was the contribution to science and engineering of Leonhard Euler, Member of the Russian Academy of Sciences. He was well versed in medicine, botany and chemistry. He even took an interest in questions of bridging the Neva. At that time, 200 years ago, only temporary floating bridges were used in Petersburg. But most of all Euler loved mathematics.

Once, sitting in his study, he tried to figure out what happens when solids rotate. He derived an unusual formula. In the language of numbers it said: when a solid body is rotated about an imaginary inner axis, it makes the extension of the axis describe invisible circles.

An imaginary inner axis, invisible circles—these are possible only in mathematics. Yes, in mathematics... but in nature too. Euler's formula helped people to understand the laws by which the Earth's axis described such a conical motion once every 26,000 years. This motion of the axis is called precession.

The great mathematician made his calculations for a uniform solid sphere. But our planet is different. It consists of different substances and is slightly oblate. And, which is more im-



Precession of the Earth.

portant, it is always under the action of specific forces.

At the end of the last century very precise instruments came into the hands of astronomers, and they used them to determine the positions of the stars in the sky. But there was something always wrong with the accuracy of their computations. At first they sought the cause of this in the distant Universe; then they "had a look" at our planet and here they found the "fumblers". They were the wandering geographical poles, simply the ends of the imaginary axis of rotation of the Earth. It was found that both the North and the South pole are continuously "wandering" as if along a helical spring, which keeps coiling and uncoiling. Their domains, to be sure, are very small: only one quarter the size of a football field. But even such wanderings have to be taken into account. Scientists are forever tracking the restless geographical poles, forever making corrections in the most precise maps.

And so our planet not only rotates like a wheel about its axis, but also sways slightly from side to side on the "invisible bumps" of the Universe.

Both the nearby little Moon and the distant immense Sun and other celestial bodies are responsible for this. Their masses draw the Earth, tending to deflect it from its orbit. Responsible for this, in the long run, are the forces of universal gravitation.

The Planet's Brake

Zacharius ibn-Mohammed ibn-Mahmud al-Kazwini died in 1283. To his descendants he left a book called *The Wonders of Creation.* Here is an excerpt from it: "Know that at various periods of the four seasons of the year and on the first and last day of the month, and at definite hours of night and day the sea acquires a certain ability to lift its waters, to form waves and movements in its waters...."

As you see, it has been known for a long time: by the Chinese inhabiting the coast of the Yellow Sea and by the seafarers of distant Iceland. The people of maritime countries always had to do with such things.

What is the cause?

"The tides follow the moon, they ebb when it breathes on them, but they grow as a result of her movements," says an ancient Icelandic saga "Rimbagla".

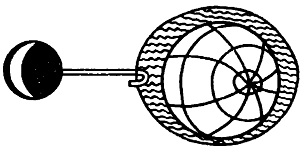
Again the Moon is responsible.

Well, and what did astronomers think about this? They have been observing the behaviour of the Earth's space companion for ages, and can tell exactly when the Moon will be at any point in the heavens tomorrow and several years from now. Arabian scientists could do so as far back as a thousand years ago. Even the Egyptian "hermit" and great astronomer Claudius Ptolemy, who lived twenty centuries ago, could give the right answer to that question. But when astronomers compared their calculations with the results of observations made in antiquity, they discovered a singular natural phenomenon: lunar eclipses occur today at shorter periods than in the past.

Facts are facts. Scientists made corrections in their calculations, taking into account the Moon's "haste" and tried to account for it.

"If the moon is 'fast'," they reasoned, "then the Earth is 'slow'. And if the Earth is 'slow', something must be hindering its rotation. Perhaps it is the tides, which also depend on the movements of the Moon?"

That suggested that our planet has a brake of its own, which was the conclusion the astronomers came to. This brake is far up in the sky and also operates according to the law of gravitation. The Moon attracts the liquid shell of the immense World Ocean, and the friction of the tidal waves along the rough ocean floor just slightly slows down the rotation of the Earth.



The Moon attracts the World Ocean.

While the tides are high in some parts of the planet, they are low in others. They can be very high only in oceans and open seas, where there are great expanses of water, but not in enclosed, small seas surrounded almost entirely by land.

The famous investigators of the laws of the Universe Galileo, Newton, Euler, Laplace, and others had long before calculated mathematically and explained the phenomena of the tides. Sir George Darwin (son of the naturalist) was the first to choose another way to attack this problem.

And Again Calculations

Probably the great naturalist and traveller Charles Robert Darwin found it difficult to understand his son's enthusiasm. How could a problem as old as the hills, the problem of the tides, interest young George Howard?

He spent most of his life at Cambridge, first as a student, then as a professor. And at Cambridge, in the cellar of his laboratory, he set up a pendulum to study the Moon's attraction. But though he enclosed it in a double-walled protective shell with alcohol and water in the space between the walls to protect it from temperature fluctuations, his apparatus turned out to be too sensitive. Only shifting from foot to foot at a distance of several metres from the "lunar force" meter would change the pendulum's position. Under such circumstances how could one know what was due to the Moon's attraction and what to other factors?

And so, like his predecessors, George Howard

Darwin sat down at his desk, took up his pen and started calculating.

His theoretical computations showed that 57 million years ago the Moon had been right next to the Earth. For almost sixty thousand milleniums our planet's space neighbour has been trying to go off into the Universe. It keeps receding from the Earth, slightly retarding the latter's rotation all the time. Professor Darwin wrote about this and many other things in his book *The Tides and Kindred Phenomena in the Solar System*, first published in 1898.

A lot of time has elapsed since then, and many things have changed. Only the tides continue to upheave the surface of the waters as before. High tides give way to low tides. For example, at the coast of Brittany tides make the sea level vary by from 5 to 7 metres, and in the Bay of Fundy between New Brunswick and Nova Scotia in southeast Canada the tidal range sometimes is 16 metres. Men have already learned to utilize their energy. There is a tide power station in France, and a similar station is now under construction near Murmansk in the USSR.

Tides are a very complex natural phenomenon. Not only the Moon but also the Sun and even the Earth itself are responsible for tidal phenomena. That is why scientists of many countries are still trying to solve this problem. And as before, tides are still discussed from the professor's rostrum at Cambridge. At present Sir Harold Jeffreys is working on them. "To Sir George Darwin, the father of modern cosmogony and geophysics," reads the dedication of his world-famous book *The Earth*.

Incidentally, this did not keep Jeffreys from reviewing critically some of the propositions of Darwin's theory. He figured out that in the course of the last 120,000 years the day has become only one second longer. He even tried to find where the main brake of our planet is situated, and came to the conclusion that it was concealed in the shallow Bering Sea. Its waters do more than half of all the friction work against the sea bottom. But Jeffreys' theory also soon found opponents. Soviet scientists established that the Bering Sea is much deeper than the British geophysicist thought. And this means that his explanation does not solve the problem.

And again scientists calculate the slight changes in time periods due to tidal friction. And they find: "During the last five centuries the Earth's rotation rate has slowed down by thousandths of a second."

You may remark that that can hardly make a difference.

N. Pavlov, one of the oldest astronomers of the Pulkovo Observatory, thinks it can. If the tides are a brake, braking may be the cause of earthquakes. To predict the moment the Earth is slowing in its rate of rotation means to foresee the probability of shifts in the Earth's crust.

One More Riddle

This happened in one of the countries of Western Europe. An institute of precise measurements had a very exact timepiece, one of those known as quartz clocks. The inhabitants of the country all set their watches by it; the quartz clock was never wrong and always trustworthy.

But once the incredible happened. The clock suddenly changed its movement. Moreover, all clocks went wrong at the same time and to the same extent. What had happened? Nobody knew. The precision of the clock was checked several times, but always with the same result: it was very accurate.

Then scientists began to observe closely the puzzling behaviour of the most precise timekeeper. Soon they found that such things may happen again. And all the timepieces always make the same error. Then the reason is not within them. "The clocks always run uniformly," reasoned the scientists, "but we compare their movement with stellar time. And any change in this time is associated with the rate of rotation of our planet. Maybe it is the planet that is to blame? Probably the Earth may suddenly now slow down, now begin to rotate faster. But why?"

"Because the atmosphere above the Earth moves in various directions," suggested some. "In summer the sun heats it more, in winter less. The atmosphere either expands or contracts. Thus, the 'atmospheric brake' now slightly retards the rotation of the globe, now eases off and stops hindering its rotation."

"But what if the magnetic field is to blame?" said others. In July, 1959 there was a flare on the Sun. After this the Earth changed its rate of rotation about its axis. The same had been observed in February 1956. Then artificial satellites sent far out into space recorded: "Our movement is sometimes perturbed by solar flares." And so, the impetuous flow of invisible solar particles rushing into the magnetic field of the Earth may convert this field for some time into a "celestial brake".

Thus was discovered another cause of the nonuniform rotation of our planet. But so far this is only an assumption. There are still too few facts. Too little is known about the uncertain rotation of the globe. And that is why it remains a puzzle.

A "Live Belt" on the Earth?

Below are clouds, but above the mountain pass blazes the Caucasian sun. You get a feeling as if you were on a beach. Only woolen socks and warm boots remind you of the permanent snow all around and underfoot.

"That's all right, I'll hold out," a young tourist reassures herself. Perspiration runs down her forehead and cheeks and dries saltily at the corners of her mouth. The last metres are difficult, but one second more, and here is the unforgettable! The ocean of the Earth's surface around. Motionless waves of mountains and white glaciers. The spray of the sun's rays and the shining blue sky! In a moment the girl forgot her weariness and recited delightedly:

"There, down below, are valleys,
There is life,
But here, a motionless eternity..."

Hearing these words, one of the mountain climbers, a geologist by profession, finished for her: "In eternal motion moves forever." Then he said:

"You know what I think when I look at these mountain chains, these huge fragments of bygone epochs? No! They're not lifeless. They are very much alive. Of course, they live a life of their own."

The geologist gazed thoughtfully over the motionless mountains and continued:

"See these snow-capped peaks here. Beyond them you see black cliffs and valleys. Still farther south begin mountainous countries. These countries form a wide belt encircling almost the entire earth. They are situated mainly between the thirtieth and fiftieth parallels."

"Well, what if they are?" said the girl, now looking curiously at her companion and thinking: "Is this an examination? Or maybe he wants to tell me some interesting adventures?"

But the geologist again asked her:

"You probably know that the most dramatic earthquakes and volcanic eruptions have occurred and still occur in Japan, Iran, on the island of Sicily, in Mexico and in Chile? All these countries are also situated between the thirtieth and fiftieth parallels."

"Now that is a strange thing," said the girl. "You mean that our Earth has a special belt, a live one as it were? Is that right?"

"You see, I could hardly say so for certain. Earthquakes occur in other parts of the globe too. Their main cause is the action of the internal forces of the Earth. However, the opinions of those who give preference to external, so-called cosmic forces, are also noteworthy. The existence of what is called a "live belt" on our planet is associated by some scientists with its nonuniform rotation. The globe is known to be slightly oblate. It was probably flattened by its own forces of rotation. Their magnitude depends on the rate at which the Earth revolves about its axis. It has been found that the rate of rotation keeps changing slightly all the time, and this should also change the forces of rotation, known in mechanics as centrifugal and centripetal forces.

"To make it clearer, here is an example. When you set a spring top spinning it contracts. Then it begins to spin slower and slower, and its surface moves inwards, as it were, at the plane of rotation, and outwards at the ends of the axis.

"A similar thing is probably experienced by our great globe. Retardation of its rotation, perhaps, causes bulging of mountains, and creates depressions, the more so that the rotation is not uniform, being now slower, now faster. Couldn't that rearrange and shift the interior parts of our planet?

"Incidentally, the waters of the World Ocean also move now toward the poles, now toward the equator. It has long been known that the Gulf Stream in the Norwegian and Greenland seas swings like a swinging pendulum: eastwards to the shores of Norway, then westwards back to Greenland. This is probably one of the results of the nonuniform rotation of our planet."

The geologist was quiet for a while, then seeing that the girl was waiting for more weighty arguments, he continued:

"Measurements have long established too, that on the Earth the northern countries are rising. Iceland, Sweden and Canada are rising. The southernmost continent Antarctica is also growing slightly upwards. But in Africa the Earth's surface is sinking at the equator. And America? There the famous Amazon flows along the equator. At one time a small rivulet Tocantis used to fall into it. Today, owing to the sinking of the Earth's surface in that district it has become a deep and wide river. And the Amazon itself, is this not why it became the greatest river in the world?"

That was the end of the small lecture on the "live belt" of our planet. The tourists went on. But the geologist had not told everything. He had not mentioned that there was a great deal seekers of knowledge could see in the northern latitudes. It is not by accident that the north shores of many lakes in Finland, Karelia and Siberia are high while their south ones are low and swampy.

It is no accident that in the course of the last quarter of a century the town of Barabinsk in western Siberia has risen one and a half metres above Omsk. This was due, as some scientists think, to sedimentary rocks of the Earth's crust sliding downhill, as it were, towards the north. It was there that immense folds, petroleum-containing domes, formed in the Earth's interior.

Perhaps this is also a particle of the great mystery which we are only beginning to understand?

Columbus' Cunning

Columbus' ship sailed the waves of the Atlantic. Water, water, water everywhere; not an island in sight. Only the compass needle as a guide and it showed: "Steady so!"

But suddenly, on September 13, 1492, the faithful needle changed its direction, swerving to the west. The helmsmen determined the ship's location by the sun, and oh horror! In four days Columbus' caravel had veered off its course almost eleven degrees.

So they were sailing in the wrong direction. But where? Was there any coast there? Maybe death from starvation awaited them.... The sailors demanded that the ship be turned back.

That dark southern night Columbus lay sleepless, tossing from side to side and thinking: "Give up my dream to discover fabulously rich lands? Never! Why, it has been the aim of my life! And now to lose all because of the crew's mutiny?" Then Columbus decided: "Better a useful lie than a harmful truth."

Just before dawn he crept unnoticed to where the compass stood and turned the compass card with its scale so that the needle looked as if it had returned to its former position.

In the morning the sailors looked at the compass and felt easier. And their admiral walked up and down the deck smiling, and repeating to everyone: "You see, during the last few days the North Star has shifted in the sky and that's what threw the needle out of alignment."

That was something the sailors could understand because from childhood they had been taught that there were mighty forces in the distant stars.

They believed their captain and agreed to sail on. But when the expedition arrived in the New World Columbus himself was greatly surprised. What puzzled him was that the needle again pointed due north; as if nothing had happened, as if there had been no need to fool anyone or move the compass card.

Thus was it first observed that compass readings could change differently at different points of the globe. People found out that the compass needle does not always point due north.

But what affects it? That was the second puzzle.

A Magnet Weighing 6,000,000,000,000,000,000,000 Tons

It was detected by Queen Elizabeth of England's physician, whose name was Gilbert. Of course he could not bring this magnet into his laboratory. He studied its smaller twins: iron balls, which he magnetized and used for carrying out various experiments. Then he wrote a book with the strange title: *On the Magnet, Magnetic Bodies and the Great Magnet of the Earth*.

So, in 1600 people found out about the discovery of the Earth's magnetism. That is what acts everywhere on the light compass needle. But why does it not always point north?

Gilbert could not find the answer to this riddle. And only later did it become known that simply the northern magnetic pole is rarely in the north. Scientists found it. Just now it is displaced almost 11.5° from the north geographic pole towards the Pacific Ocean. This displacement—the angle between the magnetic and geographical meridians—is the magnetic variation which Columbus in his ignorance did not take into account. The north magnetic pole is not due north now, but at the northern edge of the Canadian archipelago. If one stands on it the magnetic needle will point vertically downwards, showing the direction of the magnetic axis. At other points of the globe the magnetic dip is naturally smaller.

The magnetic axis pierces the planet like a needle would pierce an apple. One end of it is north, and the other south. The latter is in Antarctica. You cannot lay your finger on this axis, for it is invisible. And invisible lines of force issue like a gigantic fountain from its pole. But are they really so invisible? The little compass needle "perceives" them, and it has helped investigators to solve the mystery of its displacement at various points of the globe.

The Axis Vibrates. The Poles Wander

From year to year investigators have carefully recorded the readings of the magnetic compass needle in special logs. At first this seemed quite useless. The area of the city of London, where the measurements were made, is not so large that the needle should give different readings. But let us see what it showed over a few hundred years.

1540. The needle deviated almost 17 degrees east from the geographical North Pole.

1600. About 11 degrees east.

1720. Same deviation west.

1900. 16.5°, again west.

In 1960 it deviated almost the same as 400 years before, but now to the west.

The zero geographical meridian passes near London.

Such measurements were carried out in Leningrad too. Here passes also a specific meridian, the Pulkovo meridian. In 1720 in Petersburg the needle turned 3.5° west from the geographical North Pole. One hundred and eighty years later it pointed almost due north. In 1956 the compass needle deviated 6.8° east. And four years later it deviated to the same extent, but now west.

Thus, the magnetic pole does not stay in one place. The magnetic axis also vibrates. Like the rod of a toy top spinning over the floor, but much, much slower. It draws a curved line on the Earth's surface, the invisible trace of the poles' wanderings. So was uncovered one more secret. But the disclosure of this secret brought up another.

Unexpected Calculations

Do you know how many magnetic axes there are? There is only one for all the continents. This would be the correct answer.

But the results of paleomagnetic measurements for past ages show that America seems to have one axis and Europe and Asia another.

This suggested that during the last hundreds of millions of years of the Earth's history the American and Eurasian continents have moved apart, leaving thousands of kilometres between them.

But is this view correct? A few decades ago it was easier to agree. At that time many people were carried away by the hypothesis of the German scientist Alfred Wegener, who claimed that the continents are "afloat", like icebergs at sea. Only the "sea" are the pliable masses of the Earth's interior. Subsequently weighty evidence appeared against this hypothesis. Then, or rather now, some scientists are again inclined to think that maybe Wegener was right. At least such is the conclusion the Soviet workers A. Khramov, V. Rodionov, and R. Komissarova might have arrived at. After studying the path of the magnetic field in our country they figured out that Siberia had turned with respect to the European part of the USSR through an angle of 40°. At the same time it had shifted, as it were, three or four thousand kilometres to the southwest. That happened almost 600 million years ago. There are many who even now think such calculations very surprising. However, this strange arithmetic goes further.

Anomaly—Irregularity

Everybody knows that the globe has two magnetic poles. But Soviet Arctic investigators were on the verge of adding a third one. They really did not believe it themselves. Still, in the eastern Arctic Ocean the compass needle kept stubbornly turning away from the old magnetic pole and pointing to a "new" one. Now what was the matter?

In 1948 a special expedition was dispatched to those uninhabited regions, and it found huge mountains at the bottom of the Arctic Sea. Thus was discovered the now famous Lomonosov submarine ridge. It was the magnetic rocks of this ridge that attracted the little compass needle, like the magnetite ores in the centre of the country, in the Belgorod and Kursk regions.

These are regions of anomalies, where the compass needle behaves very erratically. The word "anomaly" comes from the Greek for "irregular" or "abnormal". There are very many such "irregularities" on the Earth, and each of them acts on the compass needle with its magnetic force.

Following a decree by Lenin geologists decided to solve the mystery of the Kursk anomaly. Into the very first hole they bored they lowered an ordinary steel drill and pulled out a magnetic one. It attracted nuts, wrenches and other iron objects—a total of about 30 kilograms. Such was the magnetic force of the Kursk iron ores—3 to 4 times greater than at the magnetic poles of the Earth.

Geologists long ago noticed the "weakness" of the compass needle for local anomalies and now use sensitive instruments called magnetometers for ore prospecting. These instruments have helped to discover the seemingly impossible.

After the Great October Revolution investigators began to frequent distant Angara. Some were concerned with building power stations on its forbidding rapids, others came in search of mineral wealth. Among the latter were prospectors armed with magnetometers. For a long time they wandered up hill and down dale among the mighty pines and slim birches. They made lengthy studies of the distant environs of the ancient town of Bratsk. And quite frequently they observed a very strange phenomenon: the north end of the instrument needle was repelled instead of attracted by the magnetic rocks.

When, on their return, the prospectors told the scientists about this, they were not believed on the grounds that their reports "contradicted the laws of nature." But some time later another expedition was sent to the Angara taiga, and it very soon established that there had been no mistake.

Then some scientists suggested that perhaps lightning was responsible, and that atmospheric discharges had reversed the magnetism of the ore.

"That's absurd!" others rejoined. "Just think how much lightning would be needed to do that to such a large area and such thick layers of magnetic ores! But earthquakes may be the cause!"

"That is very unlikely," said still others. "Most probably there are various kinds of magnetic ores there. One kind got magnetized first, and it induced the reverse magnetism in the other."

This probably is the closest guess. But will it suit everybody? That none can tell so far. But the same phenomenon has been observed in cold Iceland, in hot Turkmenia and in other localities.

And though these strange ores of eastern Siberia are already being mined by the Korshunov Iron and Steel Plant scientists are still arguing.

New Oddities

A magnetized object heated to 700-800°C loses its magnetism. But it has long been known that many rocks, including magnetic ones, formed at very high temperatures. And so...

Now let us try to get things straight, starting from the simplest phenomena. If we hold a steel needle across the poles of an ordinary horseshoe magnet and then approach it to other needles, the latter will immediately be attracted to it. The needle itself has become magnetic or magnetized, as we say. Our Earth is also a magnet and its rocks imbibed its invisible forces as they cooled down, and so thoroughly did they imbibe then that they continue to this day to attract iron objects such as the compass needle.

Only high temperatures can again deprive them of this force.

To verify this, geologists decided to examine volcanoes. Ever since the globe has been in existence, volcanoes have erupted now here, now there. They pour lava out on to the mountain slopes, and the molten rock spreads like dough in all directions. Nor is this surprising, for its temperature is 1000°C. Then the lava cools down and this is when it begins to become magnetized. It retains the magnetic forces of bygone epochs for millions and millions of years. Volcanoes erupt again and again, and each time the fiery masses pile up layer after layer. So are formed the pages of a rock book.

Geologists approximately know the age of each layer. They can open it up and bring it before a magnetometer, the needle of which then shows the direction of the north and south magnetic poles at the time that layer was formed. Geologists have perused the rock book, reading its pages again and again, and have discovered new oddities. They found that the axis had probably reversed its direction, that there was a time in the past when the south magnetic pole was in the north, and the north, in the south.

This is supported by another "book", that "imprinted" in the sea. For millions of years tiny rivulets and large rivers have eroded and undermined rocks and carried particles of the latter, including not a few magnetized ones, into the sea. Like tiny compass needles these particles rotated, fluctuating until they pointed along the force lines towards the magnetic pole. Then they fell to the bottom, forming a sediment.

Time passed and the bottom of the sea rose and became dry land. Geologists started studying the sedimentary rocks. They determined their age and found from the directions of the magnetized particles how compass needles would have been deflected in those far-off times.

In this way it was noted that approximately once in a million years the north and south magnetic poles change places, a change which probably takes only a few tens of thousands of years and occurs somewhere in the middle of the period. For 500 thousand years the north magnetic pole stays in the north, and then goes south for the next 500 thousand years. More oddities in behaviour of the magnetic poles. But this is not all.

The magnetic forces of our planet are of a definite magnitude, called field strength by scientists. This strength is very low, only 1/100 or 1/200 that of a simple horseshoe magnet. Still it must be investigated. For example, it is essential to know whether it has always been constant.

Bricks Supply the Answer

Two esteemed scientists, E. Thellier and O. Thellier, had no intention of demolishing the Versailles Palace. All they took from it was 16 bricks. Before that these scientists had visited the ancient town of Tours, where they had also "pilfered" 12 bricks from the famous house of Tristan. They had done the same at a castle in the city of Lille.

Were they antique collectors? By no means. E. Thellier and O. Thellier were studying the magnetic field of the globe, albeit in quite an unusual way.

Some think the strength of this field has always been constant. Others say that the magnetic strength also varies. Who is right?

It was this problem that the Frenchmen were trying to solve. To do so they did not study rocks like the geologists. They believed that rocks might have been displaced due to earthquakes and that red-hot magma might have penetrated the cracks in them more than once. This would destroy any primary magnetism. Besides, it is very difficult to establish the exact date of formation of rocks and volcanic lava. The error might be thousands and even millions of years. And how was anybody to know what could have occurred in that time?

But bricks are different. The bricks for the Versailles Palace were baked in 1750, and those for the castle in Lille, in 1465. There are documents to support these dates. The bricks were baked at a temperature above 600°C. This can be confirmed by experts. Hence, we know exactly when the bricks started to be magnetized.

Then the builders put them in the walls of the buildings, and nobody touched them, so they retained their magnetic properties unchanged until the Thelliers came and took them out. The scientists heated the bricks and cooled them as when they were originally produced, not forgetting to connect them first to special instruments. They recorded the results of their measurements on charts and obtained magnetization curves for the cooling period and demagnetization curves for the heating period.

From these curves they easily determined the strength of the Earth's magnetic field in the 15th and 18th centuries.

Well, suppose that is so. But what about earlier times, say, thousands of years ago?

To answer this question the Thelliers visited the ruins of ancient Carthage.

Carthaginean Vases

Almost 2,500 years ago Carthage was a big trading city. Its inhabitants practised various trades. Bakers baked bread, smiths forged weapons, and potters fashioned and baked earthenware. It was this earthenware that the investigators of the magnetic-field riddle had come to find.

Once they dug up a vase, connected their instruments to it, heated it to redness, and cooled it. Then they plotted their graphs meticulously. But to their surprise and chagrin unusual breaks appeared in the curves. Had they travelled all the way to Africa only to find they were wrong? For a long time the amazed investigators examined the cooled vase, fingering its thin walls and turning it over and over. Finally they guessed what was wrong: it was the coloured ornament, an ornament consisting of one brown and two green bands. To fix the colours the potter would have had to reheat the vase, and it was this second heating that gave the breaks in the curve.

Thus, studying the strength of the magnetic field in different epochs the Thelliers found a clue to the secrets of this ancient skill. From their graphs the scientists could determine exactly the temperature to which the pots had been heated in those far-off times. And from the directions of the magnetic force lines fixed inside the material of the vase they could tell exactly how it had been placed in the kiln to be baked.

But this was not the main thing. The main thing was that by their original tests the investigators proved that during the last two and a half thousand years the strength of the Earth's magnetic field has decreased almost in half. Field strength is measured in special units, called oersteds.

Now have a look at the table below. It is a result of the scientists' investigations.

City	Period	Magnetic field strength in oersteds
Carthage	Over 2500 years ago	0.76
Paris	200 A.D.	0.70
Lille	1460	0.56
Versailles	1750	0.48
Paris	1955	0.464

"Magnetic memory" measurements have been made in our country too, in ancient Vladimir and Suzdal, and in the Caucasus.

In Tbilisi, for example, the following results were obtained:

Period	1700	1750	1850	1900
Magnetic field strength in oersteds	0.53	0.49	0.47	0.45

As can be seen, the data of Soviet and French investigators coincide and now some scientists are inclined to believe that these measurements are characteristic of the entire Earth.

This discovery has another aspect, and a no less valuable one.

Time and the Magnetic Field

If you want to know when an old earthenware vessel was made, ask experts in the Earth's magnetism. They can tell you its age within perhaps 25 or 50 years. When the age is a matter of millenia this is not so important, especially taking into account that the archeomagnetic method of determining age is only coming into being. This method consists essentially in solving the reverse problem to that discussed above.

First magnetic field variations are studied in a large number of archeological finds of known age. Then the data obtained are combined into special age-finder albums, listing the changes in geomagnetic field strength during past centuries and millenia. Now, determining experimentally the magnetism of an earthenware vase and looking up in an appropriate age-finder to know when those magnetic field values existed in the locality of the find, one can easily establish its age.

A similar method can be used by prospectors. For example, there are basalts in the middle Trans-Urals, that emerged on to the Earth's surface about 200 million years ago. Basalts contain many magnetic minerals, and their magnetization differs greatly from that of other local rocks. Therefore, the paleomagnetic method can be employed to look for rocks of the same age in other parts of the Urals.

However, the possibility of solving the reverse problem is only a minor link in the long chain of mysteries of the magnetic field. What are the major ones?

Links of the Chain

In 1580 in London the compass needle deviated almost 11° east of the north geographical pole. In 1960 the magnetic inclination in the same city was 10°, but now west. Such are the "strides" of a large period in the eternal race of the invisible field. The large period includes numerous smaller, for instance, 50-year, and still smaller periods. And all of them testify to the variability of the Earth's magnetic field. There must be reasons for this variability.

It was thought that the Earth's crust was responsible for it, that the various geological processes occurring in it change the magnetism of the rocks. But you will agree that a few hundred years is hardly time enough for such geological processes. And fifty years is still less. Neither mountains nor seas could form in such a short time.

However, what is most important is that the forces of magnetic anomalies in the Earth's crust do not extend very far. An airplane carrying an aeromagnetometer at a high altitude will not detect them. Conversely, deep-seated sources of magnetism are more easily detected from greater altitudes. Magnetometers installed on artificial satellites recorded the immense East Siberian anomaly, whose source, as calculations have shown, is somewhere near the boundary of the Earth's core. But this is not all that space observations have shown.

The Moon, which makes one revolution per month, has not been found to possess any magnetic properties to speak of. Slowly rotating Venus seems to have no considerable magnetism either. This suggests that the deep-seated magnetism of the Earth is likewise related somehow to the rotation of our planet. Again the latest hypotheses coincide with ideas that have been advanced in the past.

Hence, the site of action is the core, and one of the main causes is the rotation of the globe about its axis. Thus, we have found two of the main links in the chain. Let us look for the rest.

Wandering Through Eternal Darkness

The magnetic field of the Earth "drifts". It was again the compass needle that helped to trace its many-century-long tracks. More than 700 years ago the greatest deviations of the needle possible for any given locality were recorded in Japan; 150 years later, in Middle Asia, and after another 180 years, in the Caucasus; then, 150 years after this, in France, and now, in the locality of England. The "drift" is westward, and comparatively uniform, at a rate of about 30 kilometres per year.

Now whenever a phenomenon leaves "traces" on the planet, scientists naturally try to find an explanation for it. The first to try in this case were the seismologists. They found that the Earth's core is probably liquid and that it contains a still denser inner core about 2,500 kilometres in diameter.

The inner core can be compared, very roughly, of course, with the yoke of a revolving raw egg. Gravitational forces act not only on the globe as a whole, but on its "floating" inner core as well. The latter describes a complex path inside the liquid core, and the traces of this path are the "drift" of the field, the magnetic centre shifting with the movement of the internal masses. Hence, the wanderings of the magnetic poles. For example, in about 200 years the south magnetic pole will move into Africa, unless it changes the direction of its movement. This pole is connected to the North (magnetic) pole by an invisible axis, which rotates and fluctuates about the axis of our planet's rotation, moving at different speeds in different epochs. According to some scientists, 600 million years ago the magnetic axis was "in a hurry". Some 400 million years later it slowed down. But during the last tens of millions of years it has become "impetuous" again.

Thus we have another link of the chain—gravity forces. The many-years' changes in the Earth's magnetism are like an X-ray photograph of the movement of the masses in its core. These changes coincide with fluctuations in the rate of rotation of the globe and with changes in location of the geographical poles.

Even the earthquakes and volcanic eruptions laking place in the Pacific Ocean are evidently connected with the state of the core's masses.

The densest rocks of the crust are those under the ocean waters. Accordingly, the densest part of the Earth's centre should shift in their direction.

And now imagine how the different masses would behave if our planet slowed down its rotation. Forces of inertia would appear, which would compress, shift, and break the matter of the Earth. Perhaps this is what gave rise to the Cordilleras on the Pacific coast of America? Perhaps this is what formed the great dips in the floor on the other side of the ocean? Such is the chain of interrelated phenomena that can be traced by studying the magnetic field. But strange as it seems, studying the magnetic field leads to the conclusion that the "west drift" is but an illusion, that the poles do not "wander", that all this is due to the shifting and twisting of sections of the Earth's crust. Scientists sometimes have a hard time substantiating their opinions. But the least understood problem is still

Why Does It Form?

This is the question the prominent physicist P. Lebedev asked himself more than sixty years ago. He had gained world fame by "weighing a sunbeam", by performing a most delicate experiment in which he determined the pressure of seemingly imponderable light on bodies.

In 1910 Lebedev undertook to solve the puzzle of the magnetic field. He made a careful study of small models of the globe made of different rocks and metal. In these tests, which were all alike, he rotated these metal rings and stone spheres, to simulate the rotation of the Earth about its axis.

But even precision instruments could detect nothing.

"Perhaps, they are not sensitive enough," thought Lebedev. "Or maybe the models are too small?"

The Earth is indeed millions of times larger. Again and again Lebedev sat down at his desk, and covered sheets of paper with columns of figures and mathematical calculations.

Pyotr Lebedev could not prove his "rotation hypothesis". Death interrupted his attempt to solve the great mystery. But his idea that the cause lay in rotation lived on.

Years passed. Scientists continued to ask themselves: "How does it form?" Some sought the answer in the properties of rocks, thinking it was the magnetism of iron ores that created the invisible cloud of force lines above the Earth.

Others said: "That's wrong. About 200 kilometres down from the surface the temperature of the Earth is more than 600°C, and the rocks can have no magnetism." But the reasonable rejoinder was: "Nobody is saying that the source of magnetism is deeper down." And still the other side argued: "The secret of magnetic phenomena is concealed in the Earth's centre. But what is the reason? What makes them appear?"

In 1945 the Soviet scientist Ya. Frenkel advanced his "dynamo hypothesis". Like that suggested by Lebedev, it was based on the rotation of the globe about its axis. But Lebedev regarded rotation as the main cause, whereas the main point of the dynamo hypothesis was the presence of a liquid core. It was in this "boiling kettle" that the gigantic "dynamo" operated. The raging torrents there give rise to electric eddies, and these create an intense magnetic field around them.... But here again scientists came up against a new obstacle.

The ? Remains

To generate electricity a dynamo has to have a magnetic field, and is provided with specially magnetized parts to create it. But what about the Earth? What created the initial field inside it? Frenkel's hypothesis failed to explain this.

Professor E. Bullard of Cambridge University attempted to solve this riddle. In 1950 he detected a westward drift, which gave scientists food for thought. A few years later Bullard advanced a daring idea.

The Earth's outer core is liquid, and hence must rotate slower than what lies above it. The dense inner core must also have a different rate of rotation. This is one thing.

The second is the temperature drop, which creates vertical flows of matter. A rising liquid would be deflected westward, and a descending liquid, eastward. The flows are thus twisted in one direction in the northern hemisphere and in the opposite direction in the southern hemisphere. In their motion they entrap the force lines of the Earth's magnetic field, giving rise to closed electromagnetic eddies, a toroidal field as the scientists call it.

This is the initial magnet which was missing in Frenkel's hypothesis. Now it was necessary to lay a theoretical basis. But nobody has yet been able to calculate these possible phenomena in full.

And so, the question remains to be solved.

The Search Goes on

Substances of different viscosities and conductivities, nonuniform motion—all this probably exists in the planet's interior. Taking into account, besides, the unequal rotation of the parts of the core, it will be appreciated that very complex annular eddies may arise there. This idea was suggested recently by the Soviet scientist B. Tverskoi.

At the top boundary of the core eddies form something like a rotating vortex, which draw the force lines of the main geomagnetic field inwards. They drag them into the interior, and for this reason self-excitation continues uninterruptedly. This goes on until the density of magnetic energy becomes equal to the density of kinetic energy of the core's liquid masses. So will it be as long as gravity and internal heat exist because they are the principal sources of the core's movements. This seemed finally to close the chain.

It seemed to, but the Earth's core itself may be an excellent conductor of electricity and heat. Then neither a considerable temperature drop nor eddies could exist there And in general, where would the heat at the centre of our planet come from? From radioactivity? The radioactive minerals in the first tens of kilometres of the

Earth's crust are sufficient to cover the present-day heat loss of the Earth.

Finally, and this is the most important point. The upper strata of the Earth are conductive like a metallic screen. This means that they can short-circuit practically any magnetic fields arising in the interior. Still, assumptions lead on. The Sun! It also rotates: it radiates the heat of nuclear reactions; it has spots. Are they not the tails of deep-seated ring-like eddies rising to its surface? Are they not a source of very strong magnetism?

This magnetism should be several thousand times stronger than that of the geomagnetic field. But actually the Sun's magnetism is only from two to four times greater than the Earth's. The Sun is continuously "demagnetizing" itself by throwing corpuscular radiation out of its spots. And what is known as the solar wind (or solar breeze) carries the magnetic flux off into the Universe.

What then replenishes the solar magnetism? Perhaps, phenomena similar to those we are looking for in the interior of the Earth. And what if there is a sort of nuclear reactor operating at the centre of the Earth?

That is the first question.

It is supposed that the strength and direction of geomagnetism changed in the past. Might not the "dynamo" of the core have "stopped" and then started rotating in the opposite direction?

If there was such a stop, the magnetic field could have vanished for that period of time. This would have removed the "armour" protecting our planet from cosmic rays. The powerful radiations from the Universe would then have rapidly changed the ancestral traits of living organisms, killing some and giving rise to new ones.

That is the second question.

Just now they seem quite fantastic. Still we can assert that the invisible magnetic field holds not only its own secrets, but many of the other great mysteries of nature as well.

THE EC MYSTERY

Telegraph Closed

Mr. Smith came out of his house and glanced at the sky. Not a cloud. Only the Northern Lights sparkling in the zenith. "O.K.!" he ejaculated and walked joyfully up to a building from which rows of telegraph poles with wires on them diverged in all directions. He was in a hurry to congratulate his aunt on her birthday. At the telegraph station Mr. Smith pulled the door once, again, ... Closed. He took his watch from his pocket and looked at it. He was surprised. Then he glanced again at the door and saw a notice on it which read: "Telegraph closed. Bad weather." Mr. Smith slowly went down the three steps and gloomingly made his way home. He was greatly perplexed on that calm, beautiful evening.

In 1847 scientists were also greatly perplexed by the mysterious disturber of telegraph messages. But they were well aware that the situation had become critical and it was high time to make investigations.

From Derby, England, telegraph lines branched out to all points of the compass. An English scientist, W. Barlow, decided to examine them in an attempt to corner the puzzling disturber of communications. What was his surprise when he found that they carried electricity even when the telegraph was not sending pulses along them, the pressure sometimes being scores of volts per kilometre of length.

"Now how can that be?" thought the scientist. "What causes the current? What if it isn't lightning? What if the cause isn't in the atmosphere at all, but somewhere else?"

Then Barlow tried connecting the telegraph wires to the earth, and found that there was electricity in it everywhere. As a result of this discovery we know today that not only atmospheric electricity but also earth currents may disturb telegraph and telephone communications. But where do the earth currents come from?

On the Right Track, but...

Once a customer came to see the manager of the pottery factory in the city of Sofia. He was a very serious and respectable-looking gentleman, and the manager hurried to offer him a chair and, anticipating a large order, put an affable smile on his face and asked: "What can I do for you?" Then the very serious and respectable-looking gentleman asked him to make two not very large clay cylinders for him.

"And what else?" the manager asked, refusing to believe his own ears. "Also I would like you not to glaze them at all, but to make them of ordinary yellow clay," added the customer, with an unaffected smile. The manager, however, smiled no longer, but took the order, nevertheless.

A short time later the Russian scientist P. Bakhmetev came again to the pottery factory where he was given two ordinary clay vessels. Back in his laboratory he filled them with water and left them standing. A week later the vessels were empty; the water had simply flowed out through the fine pores of the vessels. Anyone else would probably have resented being sold pots with holes in them, but Bakhmetev was quite content: the potters had filled his order to the letter!

Now he could try to solve the mystery of earth electricity. Aided by his assistants, he dug two holes, in the courtyard and in the basement of his Academy. In each of these holes he placed a clay vessel, filled them with a chemical solution and immersed zinc plates in the latter. This made them galvanic cells, which he connected with wires to an instrument for measuring electricity, a galvanometer, which stood in his laboratory. The cells generated direct current, which should therefore flow in one direction only. Now everything was ready for the test. Bakhmetev stepped up to the control desk. Another moment and he would connect the wires from the cell to the galvanometer. The pointer of the instrument would come into motion, move along the scale and stop at some point. That would be the case if there were no mysterious EC (earth currents) flowing. But what if there were?

His hand moved slowly to the switch. Click! The pointer swung to the right, to the left, and then started jerking to and fro over the scale. It was quite evident that extraneous electricity was passing into the cell from the earth through the fine pores in the clay cylinders. The omnipresent EC had betrayed itself. However, this was no discovery; it was just confirmation of what was already known.

One summer's day in 1893 P. Bakhmetev was sitting on a bench in a shady boulevard, reading an old book he had received from Russia. Up and down the walks of the park passed tanned, black-haired people. The language they spoke was both similar and dissimilar to Russian. True, the scientist knew that language well, for Bulgaria, where he lived and worked, was also a Slavonic country, though a southern one. On that hot day reading a book about the chilly icebergs and gray waves of the White Sea seemed to make him feel cooler.

Bakhmetev wiped his perspiring face with a handkerchief, unbuttoned his shirt collar and was soon lost again among the ice and snow and villages of the Arkhangelsk coast dwellers near the gloomy waters of the northern seas.

Stern and colourless is the landscape of the Russian north. Only the sky flares up from time to time in a magic play of colour called the Northern Lights. Often had the sea coast dwellers admired these lights, and often had they brought trouble, diverting fishermen from their course and making them wander, lost at sea, among the cold icebergs. There is a saying among the northern coast dwellers: "Came the merry dancers and the needle did a jig." The "merry dancers" is what northerners often call the Northern Lights and the "needle" is, of course, the compass needle.

"Northern Lights, compass needles and...," the scientist broke away from the book and searched his memory with a faraway look in his eyes. At the time the Englishman Barlow was carrying out his investigations the Northern Lights were often seen in the sky. And there was even a suggestion then about the strange coincidence of celestial and terrestrial phenomena... only a suggestion.

Bakhmetev got up hurriedly and hastened to his laboratory. From now on the compass needle would help him in his search for the origin of EC.

And indeed, the compass needle has helped to disclose many secrets. Soon the scientist established that magnetic variations arise a few seconds before those in earth currents. Then he noticed that at night earth currents vary insignificantly, but in the daytime when the sun is shining, they vary greatly. Hence, there must be some connection between the Sun in the sky, the behaviour of the compass needle, the Northern Lights and earth currents. The mystery of EC seemed as good as solved.

But ...

Lord Kelvin Denied It

"Gentlemen, attention, please," said the famous scientist Lord Kelvin and looked over his audience as it gradually quietened down. On that day, December 30, 1892, he was addressing the British Royal society on terrestrial electromagnetism.

"Now to continue my proof," he went on. "You all know, of course, that the Sun may emit electromagnetic waves. These waves greatly resemble those that form when a stone is thrown into a calm lake. At first the waves are strong and high. Further on they become smaller and then disappear altogether. The Sun is probably something of a magnet, isn't it? But, gentlemen, everyone knows that millions and millions of miles lie between the Sun and the Earth. Hence the Sun cannot act very strongly on our planet. Aren't we looking too far away for the cause of magnetic storms and earth currents?

"Here is a concrete example. A magnetic storm was observed in the capital of Russia on June 25, 1885. It interrupted telegraph communications for eight hours. Now what caused it? Some think it was caused by our distant luminary. Indeed, the latter sends its energy to the Earth as light and heat. But according to my calculations, it would have to shine above St. Petersburg and heat the capital of the Russian empire continuously for four months to cause disturbances in the Earth's magnetic field. As you know, gentlemen, similar phenomena have been observed here in London...."

The famous William Thompson, better known as Lord Kelvin, spoke for a long time that day at the meeting of the Royal society. He presented a great deal of evidence to show that the cause of earth currents should be sought on the globe. Scientists agreed with him at that time, and

Bakhmetev was also convinced by His Lordship's authoritative arguments.

Bakhmetev had been on the right track, but he switched over to the idea that not the Sun, but temperature variations above the Earth's surface are the main factor in the origin of the mysterious EC. At night, thought he, it is cooler, the temperature drops and EC become weaker. In the daytime it is warmer and the earth currents increase. Last century this was considered the main factor. But what about this century?

Not the Land, but the Sea

An invisible force drove the fish towards the shore. Thousands of them, despite all their efforts, were unable to swim back to the open sea. It was as if they were reacting to somebody's command. Now the fish gathered into small groups, stood stock still for a moment, and off they swam. Slowly at first, then faster, and again slowly. Then they turned to the right and back. The invisible force continued to drive them. Where did it come from?

It was the work of scientists. Two metallic rods had been lowered into the water at some distance from each other. The rods were connected to electric sources. And now a small area of the Barents Sea was under the action of an electric field.

The experiment over, the current was shut off and the fish swam away from the shore. Now all the instruments should have calmed down and stayed at rest. But one small millivoltmeter continued to tremble as before. Its fine needle silently reported that "the fish commander" had not left the water, and that at this point it always seemed to be present.

It has long been known that thousands of fish come in from time to time to the Murman shores. They seem to swim into the nets of their own accord. What is the reason? Is it perhaps that same "fish commander" that leads them here?

When A. Mironov, a researcher from Moscow, suggested this many thought it uncanny. He supposed that the approach of herring to the shores of the Barents Sea was caused by earth, or in this case sea, currents. Though this seemed almost incredible, it had to be verified.

Soon afterwards research ships appeared among the blue ice and boundless waves of the Arctic Ocean. They were not making their way to wintering places with products and fuel, they cast no nets and did no fishing. The passengers of these ships were hunting for the mysterious EC, which were also being sought simultaneously in the blue depths of the Black Sea. All kinds of experiments were designed to study the "habits" of EC. For example, metal rods were moved from point to point around a circle, as if they were rotating around a centre like a compass needle. This revealed that EC have their own constant direction—from northeast to southwest in the Barents and Black seas.

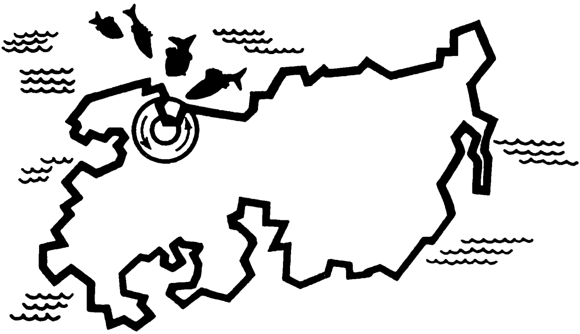
The sensitive instruments were watched day and night, and all the time EC kept reporting: "We never leave the seas, we live here. In sea water we are stronger than on dry land. True, by nightfall we get tired and, like on the firmament, we become weak and listless. Still we never go away from here. Know that the main kingdom of EC is not on dry land, but in the sea. We have disclosed many of our secrets to you, but not all of them."

Coincidence or Discovery?

Those were difficult years. Hunger and ruin everywhere. The revolution had broken down old Russia and had not yet built the new. At that time, at the beginning of the twenties, thoughts were concentrated more on procuring a piece of bread, a few nails, or a pair of canvas shoes than on anything else. But even in those hard years extraordinary scientific discoveries were made. True, the discoverers often took them for strange coincidences. They knew too little and could not account for what they observed.

Indeed, why should catches in the sea depend on the sunspots? A. Derzhavin had long been asking himself this question. He had studied the phenomena occurring on the Sun and had established a relationship between its 11-year activity cycles and the behaviour of the inhabitants of the sea. Astronomy and fish! Is it mere chance or a discovery?

More than twenty years passed. A stranger hurried along the snow-covered streets of Murmansk on his way to a meeting at the Polar Institute where he was to talk on his remarkable assumption concerning the effect of electric forces off the Barents Sea coast on the approach



Earth currents operating in the Murmansk region.

of herring. At that time this suggestion made by Mironov seemed rather fantastic.

But look at the simplified diagram. See the vortex of electric currents in the northwest of our country, in the vicinity of Murmansk, Arkhangelsk, and the White and the Barents Sea? These are traces of EC. This time it was studied on dry land, and for an entirely different purpose. This EC "eddy" map was compiled not long ago. On it are the results of recent investigations. They confirm what seemed so fantastic.

Is this again a coincidence or a discovery?

Operation "Argus"

The clock ticked out seconds and minutes. A light beam recorded a slightly wavy line on a slowly moving phototape. All was quiet. The instrument was operating efficiently. Suddenly the beams gave a convulsive jump. The line crumpled up and distended. Then it fell back again as if it had gone to sleep. The instrument continued to operate efficiently.

Soon the shift ended. Before leaving, the engineer-in-charge opened the log at the page marked August 1958 and made an entry in the appropriate place concerning the strange behaviour of EC. The same was done by engineers-in-charge in many countries of the world, all of them workers at EC research stations.

They did not know that on that day an ominous cloud resulting from an atomic bomb explosion had formed in the South Atlantic 480 kilometres above the Earth's surface. After that a bloody borealis flame flashed out in the same part of the sky. Scientists did not yet know that radio communications had been interrupted on ships sailing the Atlantic at that time. Only the sensitive EC immediately reported this to men, warning them: "Alert! Americans carrying out Operation 'Argus'."

And now let us recall the history of the discovery of EC. As much as 200 years ago coast dwellers near Arkhangelsk had noted the strange coincidence between the Northern Lights and "mischievousness" of the compass needle. Then electricity, which came from nobody knows where, began to interfere with the operation of the just invented telegraph. It was sought first in the air, but was found in the ground. This electricity was stronger when the Northern Lights appeared in the sky. In the daytime the mysterious EC raged more often, as a rule. But when the Sun dipped below the horizon, the EC calmed down. Why?

Recall also the behaviour of the fish. They obeyed the "command" of this electricity and catches depended on solar activity. It would seem there was something in common here.

In the last century scientists were inclined to believe in the wave theory of propagation of electromagnetic vibrations, according to which vibrations are something like the waves which form, for instance, when you throw a stone into water. At that time scientists paid little attention to possible tiny "splashes" which may spread in all directions.

Today we know a great deal more about these things. It has been established that invisible cosmic particles which are actually atomic fragments come flying from the Sun. Like invisible bullets these particles cut through universal space. Some of them rush earthwards and invade the magnetic field forming an invisible coat of armour around our planet.

This gives rise to magnetic storms, which are electromagnetic vibrations arising now here, now there. Some of them reach the Earth, and change into earth currents, into the mysterious and omnipresent EC, which disclosed the secrets of Operation "Argus". This atomic bomb explosion also blew atomic fragments out in all directions. They cut into the magnetic field surrounding the globe and gave factual proof that invisible particles come flying in from the Sun. In the behaviour of these impetuous particles lies one of the secrets of remarkable coincidences.

And so, one of the links in the chain is the magnetic storm, whose raging is reflected in earth currents. And in reply to this storm EC set up an internal magnetic field which is superimposed on and complicates the "stormy" external field.

This would seem to close the chain of phenomena. But mathematical calculations can tear it asunder again. If we find out the intensity of such a storm taking place in the Earth's strata, new chain links appear. Now we can determine the strength of the earth currents it gives rise to, and hence the conductivity of rocks in the Earth's interior. It depends on the composition of the conductive strata, on the pressures and temperatures in the interior.

See how far a single chain of events connected with EC has brought us!

EC Everywhere

"I guess we'll have to take this along too," sighed the weary executive. "They won't listen to me. They say they need it for the first test. Afterwards... Well, I don't know. Maybe they'll grow flowers on it." The executive sighed once more and jotted something down in his notepad.

Thus earth became one of the items on the list of urgent cargo for the Antarctic continent. Ordinary earth of the kind that lies underfoot everywhere. Of course it was needed not for growing flowers or green onion, but for looking for EC.

The trouble was that a thick shell of ice covered the distant Antarctic continent and scientists did not know yet whether the currents of the earth could "live" normally in such an "ice house". That was one of the things they wanted to find out.

And so, to begin with, they brought their earth with them thousands of kilometres and buried it in the ice together with wires to set up habitual conditions for EC. Then they connected an instrument called an earth-current finder to it, and the currents immediately reported their presence. Then the wires were transferred to the ice, and it was found that here too EC felt themselves quite at home. They "liked" both the earthen and the ice houses. It is also known that they do not like solitude, there always being a magnetic field vibrating around them.

Now these "relatives" are sought with a single instrument, in which the magnetic vibrations are caught with a wire ring, and the EC with crossed wires. Both the ring and the cross are buried in the earth and connected to a pickup. When the Earth's magnetic field changes, its flux through the ring also changes and a similar change occurs in the crossed wires. From the underground traps the signals are transmitted to the pickup. This unit has a mirror on which a light beam is always incident and reflected like a sunbeam reflection, drawing a line on moving phototape. Each signal from the magnetic field and from the EC gives the mirror a slight turn. The smaller the signal, the less will the mirror turn, and the larger it is, the more will the mirror turn. That is why the light reflection often deviates from its straight path: it records the complex traces of invisible magnetic vibrations and restless EC jumps.

In our country scientists have collected tens of thousands of phototapes with records of earth currents. Soviet research stations work on them day and night. EC finders have been placed everywhere—in the quicksands of Turkmenia, in the swamps of the Kola Peninsula, among the blue glaciers of the Arctic and in the mountains of the hot Crimea. The mystery of earth currents is gradually being unravelled, and it helps to solve the riddles of the planet Earth, a tiny particle of the boundless Universe.

THE DEPTHS OF TIME

Sensation No. I

Norway is a country of mountains, lakes and rivers. Such it remains mostly in the recollections of sociable tourists.

Came World War II. Norwegian water became a subject of discussion in the capitals of the Great Powers—now behind closed doors. Norwegian water was discussed by intelligence service men and scientists, but always very carefully. Some bank executives learned that it was almost worth its weight in gold. Rumours filtered into the press...

Then there were explosions in the mountains of that northern country, that stopped the only factory in the world producing this water. It was a load off the minds of those admitted to especially important state secrets. And how! It had to do with heavy water. The terrible sensation came to nothing, and the hitlerites had not produced the atomic bomb.

So we see, there are different kinds of water. There is normal water, a great deal of it: oceans, seas, lakes, rivers, and rivulets.

And there is heavy water—very little of this. A mere 150 grams per ton of river water. The properties of heavy water are unusual. It freezes at about +4°C and begins to boil only at 101.5°C.

Yes, there are different kinds of water. There is another kind which is still heavier. It also contains hydrogen just like normal and heavy water, but this is a special kind of hydrogen. Its atoms are almost three times as heavy as those of ordinary, and 1.5 times as heavy as those of heavy hydrogen. That is why it is called superheavy hydrogen, or tritium (from the Greek for "third"). It is radioactive and is the main component of the highly destructive hydrogen bomb. However, the latter cannot be made very easily by extracting tritium from seas, lakes, and rivers. This would require finding exactly the right drop of water in a whole sea, because thousands of millions of litres of normal water contain no more than a tumbler or two of superheavy water.

The radioactive hydrogen bomb is a terrible thing. But tritium itself can also be useful. Its radiation is very constant. Like the hand of an excellent chronometer it ticks out time in definite portions of radioactivity and keeps ticking them out as long as the radioactivity lasts.

In the course of 12 years one gram of superheavy hydrogen dwindles to exactly one half. The rest of it changes into a different chemical element—helium. For this reason 12 years is called the half-life of tritium. After another 12 years half of the remaining half will decay; then the same re-occurs with what is left, and so on until all the tritium turns into helium.

The discovery of radioactive hydrogen was sensation No. 1. Professor W. Libby was one of the scientists who discovered the secret of the "clockwork" of tritium. In fall, 1954, he travelled to New York to inform the members of the American Association of Chemists about his work. Never before had the esteemed physicist spoken before such an immense audience. Thousands of scientists came to hear him. And this also became sensation No. 1.

A Glass of Wine and an Ocean of Water

There was lots of wine here but little merriment. The men at the table were soberly and seriously discussing the merits and shortcomings of golden brandies and astringent ports. Special attention was concentrated on old wines aged in cellars, which caused serious controversy. Could physicists and chemists help to resolve it? Soon information was obtained on the radioactivity of the wines and a table of their exact age was drawn up. Now all doubt was removed.

At another meeting, now of volcanologists, there arose the question as to the age of the water vapours of fire-breathing mountains. Nobody could answer it, and again the scientists studying radioactive phenomena were called upon. They investigated the water of the Italian volcano Lardarello, but found no radioactive hydrogen in it. The conclusion was that the water vapours of that volcano were more than 50 years old. That is the time it takes tritium to decay almost completely.

And again a question which anyone might ask. If tritium is so "short-lived", its lifetime passes and that is all; there is no more of it. Of course there isn't, but...

Superheavy hydrogen is not only constantly decaying, but is also forming constantly. Somewhere at the boundary of the atmosphere space particles flying earthwards collide with the atoms of terrestrial chemical elements and form radioactive hydrogen. This hydrogen is highly active and tends, wherever possible, to unite with oxygen to form superheavy water. Then it mixes with ordinary water and falls imperceptibly as rain on fields, forests and towns. It is imperceptible to the eye, but not to special instruments. If such an instrument is brought close to a vessel containing rain water, it immediately registers the radioactivity in it. Now suppose the radioactivity of a sample of lake water is found to be only half that of rain water. This means that the age of the lake is 12 years. Of course, in practice the radioactivity of water can be studied, and its age determined, in this way only in the ideal case. One must be certain there are no other sources of radiation. And if there are, they have to be separated and allowed for.

The study of superheavy hydrogen holds promise for a large number of new discoveries. But its most important use just now is for investigating the water cycle in nature and its duration. It also helps to disclose the secrets of the wanderings of underground creeks and rivers through the dark interior of our planet. Some other riddles that can be solved this way are: how the waters move in the seas and oceans; whether they rise from the depths or descend, and how old each salt layer of the sea is.

Of course, this radioactivity "timepiece" helps mainly to uncover the secrets of a world where everything flows and changes rapidly. But what if we want to get a glimpse of more remote times, not tens, but hundreds and even thousands of years ago?

Again Visitors from Outer Space

This piece of wood had been kept in a museum. It was just an ordinary piece of wood, though very old. But physicists took an interest in it. When their investigations were over, they stated that the wooden sarcophagus of the times of the Egyptian Ptolemies was about 2,190 years old. It was then that a slave had cut down the strong trunk to make a coffin for his noble master.

From that moment the wood no longer accumulated radioactivity; it no longer afforded dwelling space to millions of newcomers from cosmos.

Not so long ago people knew nothing of this. They built houses of wood, and burned trees to keep themselves warm. Later they began to use coal as well for heating. The coal came from the older strata of the Earth, and sometimes people would find beautiful imprints of leaves and even whole trunks of carbonized plants in the coal. But that was no riddle.

People knew that the million years' history of development of the vegetable kingdom was inscribed in modern plants and in mineral coal.

One of the most important chemical elements in this kingdom has always been carbon, the principal element of coal.

And suddenly in this ever so earthly world they discovered visitors from outer space. The first to notice them were the investigators of the microworld—physicists and chemists. They likewise noticed a strange lack of coincidence. Combustion of mineral coal, the remains of an ancient wooden building, or a living plant results in carbon dioxide which, it would seem, should always be the same. But in the first case the radioactive counter is silent, whereas in the second and third it registers radioactive carbon in the gas. How did it get there, and what is it actually?

Then scientists began to look up its ancestry. And here is what they found.

At first there were neutrons, uncharged elementary particles. They come to Earth from the Universe in a stream of cosmic rays, arriving according to a regular schedule for millenia. On the way the neutrons encounter the "air envelope" that surrounds our Earth, the atmosphere which contains oxygen and carbon dioxide, but is mostly nitrogen. When bombarded with elementary particles nitrogen may change into radioactive carbon. True, only a very small amount of it does so: not more than a few kilograms of radioactive carbon is formed per year all over the globe.

But it is very active or excited, as scientists say. It does not hoard its energy, but, like tritium, combines with atmospheric oxygen. And thus the cosmic strangers again disguise themselves in "sheep's clothing", in the form of radioactive carbon dioxide.

Together with ordinary carbon dioxide plants take in a little of the radioactive variety. In the plants the latter "casts off its disguise", separating from the oxygen. The radioactive carbon "settles down" together with ordinary carbon in large trees and small bushes, in juicy grass and moist moss. Then it passes into the tissues of men and animals because they feed on the fruits of the vegetable kingdom.

But when their time comes, the plants die and stop breathing carbon dioxide. Their carbon radioactivity no longer increases. Men and animals also die, and no metabolism takes place in their tissues. No more radioactive carbon accumulates in them and that which has accumulated radiates particles and decays, changing into ordinary carbon, only half of the original amount remaining after 5,500 years. This is a much longer time than the half-life of tritium.

Thus, we can look back tens of thousands of years into the Earth's history. Such is the time scale of the radiocarbon clock. We can study the coals of an ancient camp fire and establish when the cave man started it. We can determine the age of very old articles made of wood and bone. We can find out when sea and lake organisms lived from the shells they left. Archeologists and geologists are thus provided with good timepieces with well verified correct movement.

The age of the long-life champion, the sequoia, which grows in America, like that of other trees, can be established by the annual rings on the cross-section of its trunk. When the method of radiocarbon dating was tried, the results of the two calculations were found to be compatible.

In 79 A.D. Pompeii was buried under the ashes of its neighbour, the volcano Vesuvius. This was recorded in ancient manuscripts. When the buried city was excavated, a piece of carbonized bread was found. Measurement of its carbon radioactivity showed its age to be the same. Cedar was taken from the deck of the burial vessel of Sesostris III, which, according to written records, was made in Egypt almost two thousand years B.C. Radicactivity investigations confirmed this date. Most of the puzzles of antiquity have been solved and recorded in the millenium calendar of the past by the radiocarbon dating technique.

It is even capable of establishing the dates of supernova outbursts and explosions of galactic nuclei. These phenomena increase the amount of radioactive carbon in the atmosphere. For example, the outburst of the supernova *Cassiopeia-A* in 1700 increased the amount of radioactive carbon in the trees growing at that time.

A distant star, an ancient timber road, or a church—what is there in common between them?

By studying the radioactivity of the annual rings of logs scientists can explain the details of the mechanism of great changes that took place in the Universe in ages gone by.

A Little History with an Unexpected Turn

In his youth Buffon was very fond of sleeping late. But he decided to overcome his laziness and ordered his servant Joseph to get him out of bed before six a.m. without paying attention to the threats of his sleepy master. For this Buffon even raised his servant's wages. Afterwards he would often say: "To Joseph I owe three or four volumes of *Natural History.*" Altogether this great scientific work of his life consisted of 36 volumes.

Such was the man the sharp-tongued genius and philosopher Voltaire ridiculed.

"Would a serious and clever scientist assert that mountains had formerly been a sea?" Voltaire queried. However, Buffon only smiled good-naturedly in reply.

He was convinced just the same that it was not pilgrims from Syria, as Voltaire claimed, but nature itself that had scattered seashells over the mountains of France.

Far away from Paris, in the ancient castle of Monbard, the great naturalist went even further. Of course, Buffon had read in the Bible that God had created the world in six days about 7,500 years ago. But he thought otherwise.

"At first our planet was red hot. Then it slowly cooled down, perhaps even at a constant rate," he reasoned. "It is probably possible on these grounds to determine exactly the time it took the globe to cool down. It would be interesting to know whether this time is the same as that indicated in the Holy Bible."

Buffon prepared small spheres made of a material which, in his opinion, the Earth was made of. He put the spheres in a furnace and heated them to redness. Then he observed the cooling of these tiny planet models. Finally, he calculated the age of the globe in this way and found it to be almost ten times greater than 7,500 years.

When the results obtained by the famous scholar became known at the Paris University, many were horrified. At that time church dogmas were considered infallible even in the most learned establishments of France. And George Louis Leclerc Buffon, who had stood firm before Voltaire's cutting ridicule, beat a retreat and recanted. That was in the second half of the eighteenth century.

Almost a hundred years passed. Similar calculations were carried out in England by the famous physicist William Thompson. He too assumed our planet to have been red hot at first and then to have cooled down. But the figure he obtained was forty million years.

In the nineteenth century researchers persistently sought the answer to the question: "How old is the Earth?" Various methods were devised for determining its age. Some counted up the amount of salt in the seas and oceans, others, the amount of sand and clay that could have settled in water reservoirs during the time the globe had existed, still others.... But all these methods were very approximate. From the results they gave one could conclude that the Earth was several million years old, or 10, 50 or even 100 times more, without making much of an error.

A French chemist, Henri Becquerel, did not make such calculations. He studied the luminescence of uranium salts. He would take a photographic plate wrapped in black paper, place the substance he was studying against it, and put it out in the sun. Then he would develop the plate.

But once the weather was cloudy for several days running. The carefully wrapped plate and a piece of uranium salt were put away in a dark cupboard. What was the researcher's surprise when he found the plate became fogged as if it had accidentally been exposed to light. Becquerel understood that this was no accident. Probably the uranium salt was a source of rays unknown to science. Perhaps it was an accident, though, that just at that time Marie Sklodowska was in want of a theme for her dissertation. She was eager to take up something mysterious and obscure.

"Now what if I investigate Henri Becquerel's discovery?" thought the young researcher. "I will try to find out whether other natural bodies emit rays similar to those of uranium."

Her husband Pierre Curie supported her idea. And the director of the Paris School of Engineers also did what he could to help them. He allowed them to use the shed in the backyard as a laboratory. This shed had one tiny furnace and a hole-riddled roof; no laboratory tables or ventilation hoods. But despite these difficulties, the scientists performed test after test, tens, hundreds of them...

These tests ended in the great discovery of radioactivity, the discovery of how substances radiate and change into different chemical elements, like uranium into lead.

From that time, from the end of the nineteenth century, began the epoch of intensive research to answer the question: "How old is the Earth?"

This was the unexpected turn in the old descriptive science of the globe towards the study of the secrets of invisible atoms.

What Is Relative and What Absolute?

William Smith was an observant and unbiased land surveyor. While measuring the fields and forests of his country he made a hobby of collecting various petrified shells he found in the ground. Presently he observed that the fossils found in overlying rock layers were of one kind, and those found in the underlying layers, of another. "These shells can give a clue as to the age of the Earth's strata," thought he. "Only the ages they show will be relative, enabling younger strata to be distinguished from older ones."

In 1799 W. Smith visited a man named Richardson, who had a fossil collection in his possession. The latter was glad to make the acquaintance of a collector of fossil shells. The two men compiled the first table of relative ages of England's strata.

This table was not simply an eccentricity on the part of lovers of natural curiosities. It was guarded like something precious by the London Society of Geologists, for it was the golden key to the secrets of the history of our planet.

It was while celebrating the centenary of William Smith's discovery, during the jubilee of the best and most reliable method of determining the age of rocks, even though relative, that an unexpected turn occurred.

"Radioactive decay will give mankind a new absolute measure of time," declared Pierre Curie. The members of the French Physical Society did not take his statement seriously. Two years later, in 1904, the same claim was made by Rutherford in London. Again very few agreed with the scientist. Another two years passed. The Canadian physicist, W. Boltwood drew up the first table of absolute ages of geological formations. He studied radioactive uranium-bearing minerals and determined the amount of lead they contained. Proceeding from these studies he arrived at figures ranging from 250 to 1,320 million years. But the results he had obtained were received coldly by geologists, because they were in full contradiction with their ideas.

The radioactive dating method based on the uranium-lead transformations encountered many obstacles in its many years of development. At first it was not believed, and then it was greatly doubted.

Had all the lead formerly been uranium? Suppose a mineral forms from a natural melt or under other conditions. Why could it not contain lead to begin with?

"Of course it could," replied the scientist. And so primary lead had to be separated from radioactive lead. But how was this to be done? Physicists and chemists pointed out that they could be distinguished by the difference in their atomic weights.

But this raised the question how to weigh these invisible particles of matter. The answer was to use a special instrument, a mass-spectrometer. It could distinguish between twins, whose chemical properties seemed quite identical.

However, the doubting Thomases kept on stubbornly: all right, suppose that is possible; but over millions of years natural influences of all kinds could have enhanced or decreased the radioactivity in minerals. Take, for instance, flowing water. It washes out chemical compounds and then precipitates them elsewhere as salts. Once lead is lost the rock "grows younger"; if water carries off some uranium, it "ages" prematurely. But if both of these occur the result is entirely a muddle. Where is one to start counting from, what "angle of approach" is one to take?

The believers' reply was: "It is necessary to find minerals whose constituents almost entirely remain in their places." But to this the others retorted, quite logically: "All things flow, all things change."

So what is relative and what absolute?

Air to the Scientist

The physiologist Ivan Pavlov said: "Facts are air to the scientist."

The facts of an investigation are the results of experiment. Various samples of radioactive minerals and rocks were frozen to —270°C, heated intensely to 7,000°C, compressed under several thousand atmospheres' pressure and placed under conditions where the acceleration due to gravity was increased 20,000 times. They were also subjected to superstrong electric currents and superpowerful magnetic fields. But the result was always the same. The rate of radioactive radiation never changed. This meant that the main condition, namely, uniformity of movement of the atomic timepiece, was fulfilled.

But when was it "wound up"? From what moment are we to start counting the age of the rocks composing the Earth? All of them are different, all of them formed in different geological epochs. How are we to establish a uniform starting point?

The starting point lies in the method of investigation. Indeed, it is not so much the natural substances that are studied, as the specific properties of their atoms. And these are as though fixed in three-dimensional networks called crystal lattices. These are also established facts.

Hence the count should start from the point where the atoms were "sorted out" into crystal lattices, from the time when, for example, a mineral contained in granite passed from the molten mobile into the solid crystalline state. Or when clay changed under the pressure of the overlying earth strata and perhaps high temperatures into a different rock, i.e. recrystallized into slate. To put it simply, the count should start from the day the inhabitant atoms registered into their new "homes".

There is another important condition. The crystal lattice must be strong. It must lose none of the atoms it originally contained, though they rearrange themselves slightly upon radioactive decay, when they form a new chemical element. It is necessary to take care that no extraneous radioactive impurities penetrate into the minerals and acquire the "right" to inhabit them.

As you see, the conditions are very stringent. They can be fulfilled only by studying and testing thousands of samples of minerals and rocks. But such "durable" minerals were actually found. One of them is soft mica, which splits up so easily into glittering specks. Its crystal lattice has retained both a radioactive metal and the gaseous product of its decay. This has been proved by numerous experiments, which, as we know, are facts—air to the scientist.

The K-Ar Secret

Biotite—dark mica—lay on a desk in one laboratory. Muscovite—light mica—lay in another. These mineral samples were not alike. The only thing they had in common was the method by which their absolute age was determined, namely, the K-Ar method. The results showed that the biotite was 1,800-1,840 million years, and the muscovite, 1,795-1,840 million years old. And now we can disclose the secret. Both the dark and the light micas were taken from the same locality. The time of their formation had been determined previously by the lead dating method, and found to be 1,800-1,900 million years ago.

K and Ar are chemical symbols situated next to each other in boxes 19 and 18 of Mendeleyev's Periodic Table of the Elements. The former is the symbol of the metal potassium, and the latter, of the gas argon. But the symbol K does not stand for only one potassium, but for several of them. Argon is also many-faced. Still, both potassium and argon occupy only one position each in the table. That is why the different kinds of each element are called "equally positioned", or isotopes, which is the Greek equivalent. There are the isotopes K^{39}, K^{40}, and K^{41}, 39, 40 and 41 being the masses of their atoms. Similarly, there are the isotopes Ar^{36}, Ar^{38} and Ar^{40}

If K^{39} and K^{41} are stable, K^{40} is, on the contrary, unstable, or radioactive. It is the one that changes in time into the radiogenic (meaning formed as a result of radioactive decay) element Ar^{40}.

The ratio of argon isotopes can be found with a mass-spectrometer. Then one can calculate the time needed to change K^{40} into Ar^{40}. In general, this change takes a very, very long time, the half-life of K^{40} being about 1.3 thousand million years.

The secret of transformation of uranium into lead can be unlocked in a similar way. Only in this case everything is more complicated. It is like going down a staircase with uranium as the top step and lead as the bottom step. The rest of the steps are the intermediate radioactive elements. One can also disclose the secret of conversion of rubidium into strontium, one can...

There are many radioactive isotopes in nature and the time they take to decay varies widely, from fractions of a second to thousands of millions of years. But the main thing is that these isotopes make it possible to measure the great depths of time.

There was a time when Academician V. Vernadsky dreamed of compiling a new kind of chart. Like a good calendar, it would show not the relative ages of the Earth's rocks, but their real, absolute ages. Such an accurate calendar is now being compiled for our planet.

Now we also know the age of the very oldest rocks. There are such rocks in Northern Karelia, in the Ukraine, in Siberia, in Canada, and in Africa. They are up to 3.5 million years old. And now we can answer the question: "How old is the Earth?" Of course, so far we can give only a tentative answer. There are many riddles concerning the birth of our planet that the Universe, not just the globe, keeps. And that is why scientists who sound the depths of terrestrial time are interested in celestial stones too.

For example, a study of a meteorite found in Saratov Region showed its absolute age to be 3,800 million years. But is it not possible that this is not the age of the meteorite at all, but of an unknown planet which exploded at some time in space and a fragment of which became the celestial messenger? And can meteorites themselves exist independently for so long a time in the boundless Universe?

It has been established now that the isotopic composition of the uranium contained in meteorites resembles that of terrestrial uranium. Probably the date of formation of all the bodies of the Solar System, in which those meteorites are flying, is approximately the same as of our planet, namely, 5 or 6 thousand million years.

Then why were rocks formed 10 or 15 thousand million years ago found recently in Karelia? Is this an error of investigation? But what if they are fragments of celestial bodies which "lived" long before the Earth came into existence?

To embrace the boundless is indeed difficult. One must always doubt but one must also believe.

I Believe. Do You?

Have you ever been to the Crimea? Have you seen the hundreds of interlayers of sandstones and shales? They are known as the Taurian series. The warm Black Sea often washes the debris of this series with its waves. How pleasant it is to lie in the sun on those flat stones "ironed out" by the sea.

But geologists are interested in other things. The Taurian series is literally a stumbling stone to investigators. How did it form, is one question and what is its age, is another. True, sometimes remains of ancient life are found in the deposits of the series and from some of the shells the time of their existence can be established. But this is the case only at a few points. More often the rocks are "dumb", as the geologists say. This means that it will take years and decades of searching for and carefully collecting fossil shells before enough material has been accumulated to draw conclusions.

However, we now have another way of finding the absolute age of the Taurian shales, for they not infrequently contain micaceous potassium minerals.

With this purpose in mind, I once walked through the narrow corridors of a radiological laboratory. All around were boxes of rock samples, which was rather a familiar picture to me. But then I entered a room, and here were instruments I did not know. They were set up against the wall. Glass tubing, glass flasks—the realm of chemistry. Next to them stood large installations under metallic hoods. Dozens of dials with fluttering pointers, signal lamps, buttons and switches—this was the realm of physics.

In a corner of the room, at a desk littered with calculation logs was Erikh Karlovich Gurling. I must say, it was not without timidity that I approached this reknowned scholar, Lenin Prize winner, Doctor of Chemical Sciences.

"Excuse me, Erikh Karlovich!"

"Hallo," he answered, and immediately added: "What is it?"

A straightforward question. But very simply put. Afterwards I heard that remarkable "What is it?" many times when studying the results of investigations and when, ashamed of my insufficient knowledge, I would ask him to explain something.

I was permitted to trace the destiny of Taurian shales. First of all they were pulverized and sent in powder form to the chemist's laboratory to find out how much potassium they contained and make it possible to calculate the amount of the radioactive isotope K^{40}.

Twins of these samples were heated in a special furnace to remove all extraneous gases and impurities, and then they were heated still stronger. The samples began to melt, breaking down their inner crystal lattices and losing argon gas. That is what was wanted. That the gas was a mixture of "relatives", namely, ordinary Ar^{36} and radiogenic Ar^{40} did not matter. There was also some of another "kinsman"—Ar^{38}. All this was as it should be when determining radiogenic argon. Such determinations can be made, for instance, with the mass-spectrometer, a very precise instrument.

Then lines of formulas and figures went down on paper, and finally I was given the results of the investigation. They made me doubly happy. Some of the samples had contained the remains of fossil shells whose age was known, and this meant that the potassium-argon method could be used to determine the time of formation not only of magnetic rocks like granite, but also of sedimentary rocks, provided they contained potassium micaceous minerals.

That is how I came to believe that there was one more, perhaps better, way of studying the secrets of the Taurian series.

But when I jubilantly told a very knowing geologist about this he smiled and said:

"We also tried to find out an absolute age. Found it to be 60 million years."

"So what?" I asked.

"The sample had been taken from recently solidified lava of a volcano on Kamchatka."

"So what?"

"Oh, nothing. Just still seems a bit doubtful." And the knowing geologist smiled apologetically.

But I thought that to doubt is all right, of course, but positive statements also have to be made once in a while.

Moscow ... Caution! Strong Earthquake

An unseen barrier was lowered. Unheard brakes shrieked.

"That's a motor car," said the seismologist, glancing at the tape of the pickup.

"Everything seems absolutely quiet here," returned the visitor.

The worker of the "Moskva" Central Geophysical Observatory smiled.

"I might add that our seismograph is a kilometre away from that barrier and thirty metres below the surface. Its sensitivity is commensurate with that of an electron microscope; ground vibrations are magnified fifty thousand times. What do you say to that?"

There was nothing to be said. Indeed, the Earth's quietude is measured here in entirely different terms.

For example, one fine day in 1960 Muscovites walked calmly as usual along the streets of their city. But there was no calm at the Central Seismic Station where the workers were anxiously watching the signaller scale, which was silently but eloquently screaming out the brief message: "Alert! Strong earthquake." It was an alarming warning. But no one ran away in fear; nothing in the room even budged. Only the recorder pens swung widely over the moving seismograph tapes, and a buzzer sounded sharply and died out.

Now the seismograph records no longer resembled stormy ocean waves. They ran on like rivulets. The people also calmed down. The station workers quickly went over the recorded vibrations of the Earth's surface, and compared them with the records of other seismic stations, which had been transmitted to Moscow. Thus, without leaving their offices they learned of a terrible catastrophe in distant Chile. In the last days of May 1960 new mountains and valleys formed in that South American country, new islands arose off its shore and others vanished under the stormy waves of the Pacific Ocean. Nine volcanoes that had been dormant for more than fifty years came to life all at once. Ash and fiery lava, landslides and an immense ocean tide all fell at once on the little country of Chile.

The ocean was stirred up. Even on the coasts of Kamchatka, at the other side of the globe, an immense tsunami wave splashed over the fishermen's moorages and settlements. Generated by the earthquake it raced over the ocean to Japan, to the Kuril Islands with the speed of a jet aircraft. But the scientists worked still faster. Soviet stations sent out warning of the impending danger, and victims were avoided.

Such severe earthquakes are not very frequent occurrences. Minor earthquakes happen much oftener—hundreds of thousands per year. Once every five minutes there is an ear hquake people can feel. Once every three of four days there is a natural calamity strong enough to cause destructions. And almost every year there is at least one catastrophic earthquake.

The regions of noticeable earth tremors in the Soviet Union are located mainly along the southern and eastern frontiers. But localities where the ground never vibrates under foot are much more numerous. Anyone living in the northern part of the country would most likely corroborate this statement ... but he would be mistaken.

Starting with the Chronicles

In one of the busiest parts of Leningrad, at the crossing of Sadovaya and Nevsky Streets, there stands a beautiful building, a treasure-house of human wisdom, the State Public Library. It has many reading rooms, one of which is specially for ancient manuscripts.

Let us go in this room, where unique books are kept. Here is one of them. Its title reads: *Records of Dvina Events in 7061 (1553)-7134 (1626)*. On the reverse side of its 105th page we read: "In summer, 7134, this fourth day of May, the earth trembled all over Pomorye*, on the Solovki Islands, in Ust-Kol, and up the Dvina as far as the Siysk Monastery."

This is hardly credible. Wasn't the chronicler joking? Or maybe he had grown tired of writing about ordinary things and had invented something new for a change? Why even the sensitive instruments for measuring earth tremors had never before noticed such things. But now modern instruments not infrequently report similar occurrences. Such instruments have been installed at the "Apatity" seismograph station on the Kola Peninsula.

Another chronicle entitled *The Nikonov Annals* reads: "And that same autumn, on the first day of October, on which day the great

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* Pomorye—the coastal region of the White and Barents seas.—*Tr.*

Prince was released from Kourmysh, the town of Moscow started shaking at 6 o'clock in the morning; the Kremlin, the whole settlement and the temple trembled, and many people, who were not sleeping and felt this, were struck with grief and fear for their lives."

"Trembling" of the earth has been observed even in the quiet Baltic countries. In 1775 "tables, beds and floors began to move" in Ventspils (Latvia).

"All this is ancient history", doubting Thomases will say. "Nothing like that ever seems to happen in our days." But many Muscovites will remember how in the early morning of October 10, 1940, furniture began to creak and ceiling lamps to swing in their flats. These were echoes of a major earthquake in the Carpathians, that had reached the capital.

Many such occurrences of the distant past and of recent years can be named, and they are all evidence that there is not a point on the globe entirely free from earthquakes.

Why Do They Happen?

This is a question that scientists are still asking themselves. However, the main point was understood a long time ago. "In two ways does the Earth's interior manifest its nature: one due to the efforts of bodies moving on its outside, and the other to the movements of its own interior. The external actions are strong winds, rains, flowing rivers, sea waves, glaciers, forest fires, and floods; the only internal one is earthquakes." So wrote the famous Mikhailo Lomonosov in 1763, and this is the main point.

Inside our planet there gradually accumulate forces which shift and break the Earth's crust. But there are other, minor causes.

For ages chroniclers of Georgia, Armenia and Azerbaijan have recorded various events. Nor did they forget to report about earth tremors that occurred when the moon was full in the sky and when there was no moon. Such records have been kept for almost nine hundred years. Careful study showed that the strongest and most destructive earthquakes in the Transcaucasia took place during full moon periods. It is quite obvious that the forces of gravitation played a part here.

Various phenomena occurring on the Sun may also "be included" in the mechanism of terrestrial catastrophes.

Now here is something that seems quite irrelevant at first glance. One of the creators of the first hydrogen bomb, Edward Teller, "observed" its explosion at his own home in America, by means of an instrument for recording earthquakes. Teller afterwards described his experience as follows: "After my eyes became accustomed to the dusk, I noticed that the light spot was very unstable, much more so than could have been expected to be due to the continuous vibrations of the Earth, 'microscopic earthquakes' caused by the impact of ocean waves on the continent... Finally, the time came for the shock of the explosion, and it seemed to me that that is just what happened: the light spot began to jump swiftly all over the screen."

Large and small, constant and casual phenomena—they all affect our planet, disturbing the force equilibrium in the Earth's crust.

The rotation of our planet is a constant phenomenon, but it changes and decreases in time, now contracting, now slightly expanding the body of the Earth. Could this happen without earthquakes?

The Earth's magnetism is also a constant phenomenon. But we know that the magnetic poles keep wandering. Every five or ten years magnetic inclination maps have to be revised. If the source of magnetism is in the core, then the latter is also restless. This could hardly fail to find expression in the "life" of the Earth's surface.

And solar energy! Clay on a steep river bank and other minerals imbibe, as it were, the heat of the Sun's rays. Millions of years pass and these rocks sink deep into the interior and begin to change, setting free the energy they have accumulated and thus causing additional stresses in the Earth's crust.

Radioactive decay also liberates heat inside the crust, causing the substances there to separate, the heavier ones sinking and the lighter ones rising. This gives rise to contractions and expansions, changes which the Earth's interior cannot always withstand. You often read brief reports in the press about underground shocks occurring somewhere in the Crimea, in the Kuril Islands or in Tadjikistan. These are zones of active movements of the Earth's crust, where it is often shifted in different directions. Near the Kurils major breaks occur in the Pacific floor, and the "growing" Gissar range in Middle Asia bounds on the Tadjik depression. New mountains and valleys are often born at the sites of earth tremors.

Not so long ago deep fissures were reported to have appeared in the centre of the Kyzyl Kum desert. When the scientists marked the centres of the earthquakes occurring in this region on a map, many things became clear. Here under the sands runs an extension of the Kuramin mountain range. The movement of its underground ridges shakes the surface of the desert and creates fissures. Tashkent is also in an active zone of the Earth's crust.

Earthquakes may sometimes be due to unusual causes—a storm at sea, a change of weather. These seem trifles, but it must not be forgotten that in warm and cold weather, during windy and calm spells, the atmospheric pressure changes. The air presses now stronger, now weaker, on various areas of the Earth's surface, which may disturb the force balance in the interior. That is why some researchers think that earthquakes are started primarily by minor causes.

Indeed, if some energy makes only a few particles of a substance vibrate, these particles may make all the rest of the substance move with them. This gives rise to elastic waves. They appear when fiery hot lava breaks through the rock barrier and rushes upwards to the throat of a volcano. Then restive seismographs record volcanic earthquakes. Washed out by underground waters, the ceiling and walls of a grotto cave in, and seismographs again register quakes of the ground. Such an earthquake is said to be due to collapse. A giant meteorite falls to the ground, similar, perhaps, to the famous Tungus meteorite or to that which fell on the Estonian island of Saarem, and once more the Earth's surface trembles. In January 1966 underground shocks destroyed 41 settlements in Greece. The cause was an artificial sea which had been made at the town of Kremast and added 150 tons of water to the weight of each square metre of the formerly dry land; the result was a shift of terrestrial masses and ruin.

Landslides and volcanoes, explosions and meteorites however make only minor portions of the Earth tremble. It takes mightier forces to cause earthquakes which make the solid crust of our planet shift and break. But these forces not only destroy; they give us a "glimpse" into the interior of the globe.

The Planet's Lantern

Ice, ice everywhere. Now and then an explosion would rend the snow-white silence. No, this was not a case of illicit fishing, but an "examination" of the ocean floor. Afterwards I saw a map showing mountains, ridges, and deep valleys. Man had never set foot there. Only sea creatures and fish hid in the deep fissures, rested on the mountain peaks. Still the Earth's surface had been distinctly discernible under the water layers. The darkness of the ocean had been lit up with the planet's lantern. Have you ever heard of this lantern? It is again earthquakes.

With a radio we can "pick up" distant and nearby countries. With their instruments scientists also pick up earthquake waves, both distant and nearby. The difference is that these vibrations travel not above the surface, but right through the Earth, and are called seismic waves. They travel at different speeds as they pass through layers of different rocks. At the boundaries between terrestrial strata the vibrations change their direction, i.e. are refracted. The planet's lantern flashes continually at various points of the world, now hardly visible, now very bright. These flashes come in different colours, as it were. One of the colours is transverse waves which make rock particles vibrate at right angles to the direction of their propagation. Such waves arise only in solids. The other colour is longitudinal waves, which displace the particles in the direction of travel. They are observed in liquid and gaseous substances as well as solids. The vibrations spread at different velocities in layers of different density. Hence, these characteristics can be used to establish the states and locations of deep-seated rocks. Longitudinal and transverse waves are the most important natural earthquake signallers.

By studying seismic waves, by comparing them to see how they change as they pass through the deep-seated layers of the Earth, it was found that the globe consists of three layers. The thin, uppermost layer, the crust, averaging about forty kilometres in thickness, is solid and rocky. This crustal layer varies greatly in thickness from place to place, being thicker on the continents, and mainly in mountaineous areas, and several times thinner in oceanic regions. Then comes another intermediate layer, called the mantle, which is probably very hot, very dense, and may be plastic. Inside that is the core. It is a sort of a sphere within a sphere and its boundary lies about 2,900 kilometres beneath the surface of the Earth. It is difficult to say what goes on there.

The only thing scientists know for certain is that monstrous pressures reign there, millions of times higher than at the Earth's surface. Under such conditions substances change entirely. The core probably has a core of its own, known as the inner core. In any case, only longitudinal waves pass through the outer and inner cores, and in contrast to transverse waves they can pass through liquid and gaseous substances.

The main shells of the Earth... Quite a definite concept, isn't it? But again we are far from the truth.

The structure of the deep interior is most probably much more complex than our arbitrary assumptions. To see thousands of kilometres into

Longitudinal and transverse waves light up, like a lantern, the dark interior of our planet.

the depths of the planet is but fantasy in our times. Perhaps space flights and investigation of other stars and planets will help men to understand what is taking place in the centre of their own Earth.

But as to the supposed mantle, we shall soon be able to have a glimpse into it. It conceals one of the main mechanisms of earthquakes. And here is proof. In March, 1953, Spain and the northern coast of Africa were shaken by an earthquake. Treatment of the data brought by seismic waves showed that the focus of the earthquake lay in the south of Spain at a depth of 640 kilometres. That is the zone of the mantle.

The Pacific depression is the most dangerous earthquake zone. Almost nine tenths of the total force of all the earthquakes that occurred in the ten years between 1950 and 1960 was concentrated in this half of the total area of seismic regions on our planet. Nor is this a matter of chance. In this region earthquake foci are not infrequently situated as deep as 750 kilometres.

Very important physicochemical phenomena occur in the mysterious mantle of our globe. The matter of the interior is evidently constantly shifting. The mantle, especially its upper part, is not uniform. This is confirmed by the data brought in by earth satellites. Changes in the orbits of their flight depend on the least fluctuations of the Earth's gravity. But this gravity has been found to be nonuniform. Hence, the masses in the planet's interior may have different densities.

Superdeep drilling projects are already under way both in the Soviet Union and in the USA.

When researchers get through to the mantle, many causes of earthquakes will become clear and man will even learn to prevent them. But so far all they can do is say meticulously: "First of all we must know..."

Three Questions in One

First of all we must answer three questions: where? how strong? and when?

Where—is not very difficult to find out. How strong—is more difficult, but can be established with adequate instrumentation and by the damage caused by an earthquake. It is much more difficult to answer the question when? But even in this case there is nothing insurmountable. It was noted long ago that weak earthquakes occur more frequently and strong ones less frequently. In other words, a certain comparatively constant relationship has been established between the number of earthquakes occurring and the energy they evolve. Scientists write this dependence as the formula $N=f(E)$. N is the number of earthquakes occurring on a definite area over a definite length of time, and E is the energy of the calamity at its focus. Hence, the recurrence of earthquakes is a function of their energy. This is a universal law, the use of which makes it possible to predict earthquakes at least approximately and thus to supply the answer to the question when?

There are other ways too.

The Earth's crust is constantly breathing, or trembling, as it were. It does so especially strongly before the beginning of an earthquake. If the "breathing" of the Earth is watched with especially precise instruments, say laser rays, with which the slightest inclinations and bendings of the Earth's surface can be noted, it will of course be easier to "see" an approaching earthquake.

Its beginning is accompanied by the appearance of elastic vibrations in the strata of the Earth's crust. These include sonic vibrations. Wouldn't it be attractive to listen in to the noises of the Earth's interior with highly sensitive microphones and thus to pick up the sounds of an approaching disaster?

Rock strata could be sounded, as it were, with minor explosions. In the zone where energy is accumulating for future earthquakes the properties of the rocks undergo a slight change, altering the rate of travel of elastic waves through them. If abnormalities in the time of arrival of waves caused by explosions, compared to usual conditions, are detected, make preparations for an earthquake. The amount of territory covered by such abnormalities would make it possible to judge the magnitude and depth of the future focus and hence the strength of the impending quake of the Earth's crust.

Nature itself supplies man with various predictions of its threatening attack. For example, a study of the behaviour of certain animals has shown that they sometimes sense the approach of such a calamity better than men. Another way is to study the changes in the magnetic field and in electric earth currents. Still another is to establish the dependence of earthquake occurrence on the 11- and 90-year cycles of solar activity. It is difficult to say as yet which methods of scientific prediction are the best, but one thing is quite clear, that they are real. Hence, even earthquakes will eventually cease to be a threat to mankind.

And now for a concrete example.

Only About Tashkent

Suddenly everything was in motion. Such was the first sensation of people at dawn, April 26, 1966.

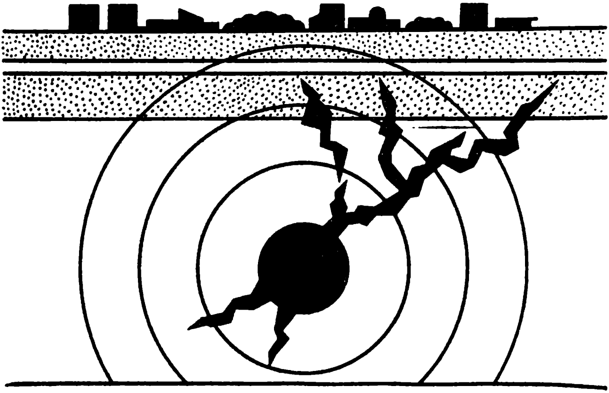
But workers at seismograph stations saw no reason for alarm. "It was, on the whole, a weak earthquake," they said. "During the Chilean catastrophe the soil shifted 2.5 millimetres even in far-off Leningrad, which is a thousand times more than was registered during the earthquake in the Uzbek capital."

"We register tremors like that in Tashkent quite frequently," said the director of the "Moskva" Central Geophysical Observatory I. Popov, "and, as a rule, they cause no damage."

Then what had happened? Why did the inhabitants of the Uzbek capital find themselves "on a mad camel's back"? The earthquake was a weak one, but buildings collapsed.

The matter lay in the focus of the earthquake. Were it deeper down or several score kilometres further off, nothing would have happened.

The shocks came from a depth of only 5 to 8 kilometres under the centre of the city. There is a deep-seated fracture at that point, where elastic stresses slowly accumulated. Then these stresses relaxed suddenly, and the rocks shifted



Faults and earthquake foci in the Earth's crust beneath Tashkent.

sharply and almost vertically along the main fracture. The energy of the underground catastrophe rushed upwards to where the little raw-brick and adobe huts of the old part of the city stood. They were literally dwarfs on clay legs and they fell to pieces. The other buildings suffered less damage.

The main earthquake, as is usually the case, was followed by aftershocks. The "Tashkent" seismograph station registered 130 aftershocks on April 26, and 317 in the next two weeks. Two months later their number had risen to about 500 and four months later, to about 700. Of course, the frequency of the aftershocks decreased as time went on, and they were hundreds and thousands of times weaker than the main shock in amount of energy liberated. "Yet, after shocks of force 6-7 occurred," will point out those who followed press reports attentively. "How could that have been?"

The point is that the foci of the aftershocks rose closer and closer to the surface. The shocks were fairly strong, but covered less and less area. It is not by accident, therefore, that many inhabitants of the city learned of a severe shock that occurred in the fall of 1966 only by radio. There was alarm only at the epicentre of the afterquake.

Scientists believe that further disturbances in the subsurface strata under Tashkent are practically impossible. Hence there is little probability of stronger quakes of the ground.

Now an institute of seismology has been founded in the city. The geologists working there study the interior of the restless foothill regions. Highly sensitive seismic transducers and microphones will be lowered into a three-kilometre hole drilled under Tashkent. They will "listen in" to the least slightest vibrations and cracklings of the rocks. And a sensitive magnetoionosphere station will keep watch over the upper layers of the atmosphere. This is also necessary because before an earthquake starts, not only the magnetic and electric fields of the Earth change, but even the atmosphere often glows. The inhabitants of the capital of Uzbekistan have witnessed such glows many times.

The superstitious have their own ideas about the Tashkent earthquake. "Girls have taken to stylish hair-does instead of braids and wear mini skirts, and this made the Earth angry," was how an old religious Uzbek explained it at the city's old bazaar.

A similar catastrophe took place in 1868. At that time there was a rock shift along the Karzhantau fault. And this happened despite the fact that in those days the girls still wore their traditional braids and long skirts.

THE PLANET'S STRANGE DISGUISE

To See the Past!

The amount of work Professor L. Rukhin did was astonishing. Not many men can do creative work at such a rate. But the scholar's life was tragically cut short and he died on September 7, 1959, at the age of 47.

A young man with a good-natured smile on a strong-willed face looks at the reader from the frontispieces of his two major books, *Foundations of Lythology*, and *Foundations of General Paleogeography.*

It would have taken others a lifetime to write such books, but he wrote them in a few years. Students, practical geologists, and scientists of European and Asiatic countries learn from these books how the face of our planet became covered with thick layers of clays, sandstones, limestone, and other sedimentary rocks. His works give us a glimpse of what will never be repeated—the deserts and seas, and the valleys and high mountains of ancient epochs, and enable one to sense the hot and cold climates of past millenia. I also studied by Professor Rukhin's books.

What are the forces that created the blanket of sediments, the many-kilometre-thick layer covering the primeval basement of the Earth?

They may be likened to two fighting armies. Internal forces form the basic relief of the planet, manifesting themselves in risings and sinkings of the Earth's crust. Even the locality of complete calm—the Middle-Russian Platform—rises at a rate of five millimetres per year, and the Moscow region next to it sinks just a little slower. But the Dnieper region is "growing" very rapidly, almost a centimetre each year.

Just imagine, a whole metre per century, a kilometre per hundred thousand years. That would already be mountains. Still, there are none there. Either the rising alternates with sinking, or very strong external forces have been at work. The latter destroy, smooth down the Earth's relief. Compared to such eternally contending giants, the activity of volcanoes and earthquakes may be regarded as the work of dwarfs.

Climatic conditions also act on the planet. On them depends the rate of chemical destruction of rocks. Tropical climate reigns over 36.2 per cent of the Earth's surface, moderate, over 27.2 per cent, cold, over 18.8 per cent, dry, over 10.5 per cent; fortunately, this leaves only 7.3 per cent for snow-bound climate.

If we ask what were the climatic conditions of Siberia 600 million years ago, we can find the answer in L. Rukhin's books, by looking at his paleogeographic maps. At that time eastern Siberia was a sea and the island of Sakhalin was part of the Asian continent. The sea waters evaporated in closed lagoons, depositing salt in their shallow parts. Such salt deposits—evidence of hot weather—can be found in the sedimentary layers near Irkutsk, which is today a district of crisp winter frost and snowstorms.

The living kingdoms also change the face of the Earth. For example, some sea organisms have built and continue to build their shells from lime compounds. When they die, they gradually form limestone layers. Anybody who has visited the Crimea has surely seen them and found fossil shells.

If the action of internal forces, stretched out over a period of hundreds of millions of years, were condensed into a five-minute film, we should see a raging sea instead of the still surface of our planet. Alongside upheavals we would see very distinct subsidences. The external forces throw and wash rocks from the highlands into the resulting depressions. That is why the thickness of sedimentary layers depends on the velocity of vibratory movements in various parts of our planet. This is the answer to the question why layers of sediments may be kilometres or centimetres thick. And the thickness of these layers explains the reverse question: "Where and when in the past did sags or upheavals occur on the Earth's surface?"

Many explanations throwing light on the history of transformations of the face of our planet are given in the works of L. Rukhin. He started from minor questions, the sizes of ordinary pebbles washed down mountain side by rivers. Only afterwards did he turn to major questions, to generalizations concerning the entire globe.

How can we see the past? There is hardly a simple recipe. One must work and work, think, be able to analyse, and have imagination, imagination of a special kind, of a kind supported by scientific facts.

A Hook to the Earth (Almost a Fantastic Conclusion)

Comparatively not so long ago our country as far as the Carpathians and the south Urals was covered with ice, as were also Canada and the north of the United States.

This fact is beyond any shadow of doubt.

About 12,000 years ago the ice melted: this is also an authentic fact.

But why did it happen?

Ludwig Seidler, a Polish scientist, made a careful study of the circumstances of this event. The explanation he found is based mainly on what would seem to be a rather unimportant fact.

In northeastern Siberia there are cemeteries of extinct animals where tens of thousands of mammoths are buried in the permafrost layers. The flesh of these animals has been excellently preserved, though under normal conditions a corpse should begin to decay in ten or twelve hours.

One might think that their corpses had been preserved because the animals lived under conditions of Arctic cold. But this is not so. Undigested remains of food were found in the stomachs of the dead mammoths, remains of cones and needles of spruce and larch, which do not grow in the north tundra.

This means that the ancient elephants lived in a moderate climate and that they perished from the unexpected cold. It means that a great catastrophe fell on the planet 12,000 years ago. What was this catastrophe?

Ludwig Seidler thinks that the Earth collided with a very large cosmic body, which made it shudder and displace. The geographic poles quickly shifted 30 degrees in the direction of the action of the outer force. The North Pole moved out of Hudson Bay into its present position, and the "ice cap" shifted rapidly from Labrador to the mouth of the Yenisei, freezing a herd of mammoths.

The equator changed its position accordingly. Previously it has passed through the highest peak in the world—Mount Everest.

That is how some regions of our planet grew sharply colder, and others much warmer. That is how the climate changed unexpectedly.

Of course, this catastrophe made the waters of the World Ocean rush as a gigantic wave into the lowland regions of America and Europe, drowning the hypothetical Atlantica and tearing through Gibraltar into the Mediterranean Sea. All this is mentioned in the works of the ancient Greek chronicler Plato. Perhaps this was the basis for the biblical legend of the "world flood".

Some scientists think that in the past the geographical and magnetic poles coincided, but nowadays they do not because they have moved many hundreds of kilometres apart.

But what if it is just that the magnetic axis has not yet caught up with the geographic axis, being closer as yet to their precatastrophic direction?

The Polish scientist even indicated the landing site of the supposed planetoid which had landed such a hook on the Earth, as boxers would say. He considered this site to be not far from the Bahama Islands.

A daring, almost fantastic conclusion, isn't it?

Underwater Scars

"Flying around the globe I saw with my own eyes that there is more water than dry land on the surface of our planet," said Herman Titov, Cosmonaut-2.

Three quarters of the Earth's surface is covered by the waters of the World Ocean. They conceal a planet essentially unknown to us. Unusual relief, craters like those on the Moon; thousands of these volcanic cones rise, for instance, from the Pacific floor. Enormous mountain chains. There is a mountain system under the Atlantic Ocean three to four thousand metres high, covering an area one and a half times that of the Soviet Union, one of the largest countries in the world. But it is not this that astonishes researchers.

Fissures and ruptures cut up the floor of the oceans like knife slashes. The total area of the Earth's unhealing wounds concealed by the waves is equal to that of all the dry land on the globe. And the land itself was at one time under the water, as is evidenced by sedimentary strata, which cover 95 per cent of the continents. They were deposited in former seas in the course of millions and millions of years.

The same is occurring now too. Where the present-day World Ocean is older, where its floor is smoother, its sedimentary stratum is thicker.

But in the regions of the gigantic scars on the body of the Earth, which take the form of rift ridges, there is no sedimentary layer at all. This might suggest some recent catastrophe on the globe. But if this were so, there should be a comparatively uniform thick layer of sediments on the even ocean floor around bare peaks. Actually, the thickness of the sediments increases gradually. Hence, there was no catastrophe. Then what was there? This is unknown. However, to research scientists the unknown is a relative concept.

Once in his early youth Professor Earnest Kraus of Munich had an all-night talk with Alfred Wegener, after which he became an adherent of the "floating" continent theory for the rest of his life.

In June, 1966, he attended the Oceanographical Congress in Moscow, a grey-haired dried-up German, seventy-seven years of age, outwardly a pedant. He argued with conviction: "Two or three thousand million years ago there was a great continent in the southern hemisphere, which we call Gondwana. Heat flows from the interior broke it up into pieces, which became our continents and "floated" to where they are now. The traces of these faults still exist on the ocean floors as gigantic scars on the Earth's crust."

Have the continents "dropped anchor" today? No, they are still moving. Sections of the Atlantic floor move horizontally an average of a half a centimetre per year. Iceland continues its "voyage". The block of the Earth under India is "moving in" on Asia, evidence of which can be seen on any map in the form of the Tien Shan, Pamir, and Himalayan Mountains. At least, that is what some investigators of the planets' underwater secrets think. The common cause of these movements may lie in the bulging, the expansion of the globe.

If We Are Observant

I. Kirillov's life was hardly what one might call a happy one. Born in a distant hamlet beyond the Volga he went to school at twelve, but studied only for 4 months. That is one fact.

Another is dated January 1958. There was unusual animation in the auditorium of the Moscow Society of Naturalists on that day. A researcher in the rostrum was telling the scientific luminaries of Moscow about his hypothesis of the Earth's development, about the origin of its continents and ocean depressions. Such are two events in the life of one man.

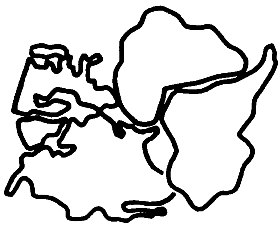
It all began as if by accident. Once while examining a photograph of the ribbon-like Martian seas it occurred to Ivan Kirillov that the beginnings of the Earth's oceans in the distant past might have been very much like those in the photograph.

Kirillov decided to look into this question in greater detail. He cut out "patterns" of the continents from ordinary condenser paper after an ordinary school globe. He made a sphere about half the size of the globe and arranged his patterns on it. Then began the most intricate and tedious part of the work. It took two or three years before he was able to reproduce on his model all the necessary scientific data, namely, climatic zonality, the structure of the Earth's crust, etc. He worked independently, knowing nothing of other scientists' detailed investigations. And independently he came to the conclusion that our planet is not probably contracting, as was thought previously, but expanding. "Such an assumption is going too far," some of our readers may think.

But let us do some simple geometry. Move little outline patterns of the continents together on the globe, taking into account their flooded parts, known as shelves. We decrease the volume of the Earth, as it were. The result is shown very schematically in the figure. It again seems to confirm Wegener's ideas.

As you see, observation arouses thought, and thought leads to discovery.

For instance, take a classroom globe. We are quite familiar with it and we even seem to know a lot about it. But roll it along the table and watch it attentively. You will find that whenever there is water at the top of the globe, the point at which it touches the table is dry land in 19 cases out of 20. Indeed, opposite the Arctic Ocean is the Antarctic Continent. Opposite the



The outlines of the continents fit into each other if moved together. Maybe Wegener was right?

Pacific Ocean is Africa and Europe, opposite Australia, the North Atlantic, opposite North America, the Indian Ocean. And only South America has the dry land of Southeastern Asia opposite it instead of water. Now carefully examine the classroom globe, this tiny model of the Earth. It has one more interesting regularity: its continents taper southwards. Hence the southern hemisphere is oceanic and the northern hemisphere continental. Isn't this related somehow to the rotation of our planet?

At the turn of the century the German geographer Albrecht Penck decided to ascertain where the highest peaks on Earth were, and it is not impossible that he also started with a classroom globe. He found that the highest mountains in the hemispheres are concentrated around 30° north latitude and 30° south latitude. It might be appropriate to recall here that as far back as 1877 E. Bykhanov, a Russian scientist, wrote: "The more the rotation of the globe slowed down, the more mountains appeared on its surface." And it has been rotating about its axis for thousands of millions of years already. It rotates, fluctuating, almost imperceptibly slowing down its movement, and speeding it up again slightly from time to time.

Moho

There were seven wonders in the world. The eighth was engineer Garin's shaft on Gold Island. "... The most important part of the work, drilling, was done by coordinating the action of hyperboloid rays, cooling with liquid air and removing the rock with elevators. Twelve hyperboloids of a special design, energized by electric arcs with shamanoite carbons pierced and melted the rock, a stream of liquid air instantaneously cooled it, breaking it into tiny particles which fell into the elevator buckets. The combustion products and vapours were exhausted with fans."

This is an excerpt from Alexei Tolstoy's *The Garin Death Ray.*

A solitary island amidst the Pacific Ocean, hemmed in with barbed wire and surrounded by an impenetrable guard. A shaft is being sunk here into the Earth's interior to reach gold. Suddenly there comes a moment when gold, like oil, begins to gush from the ground of its own accord. Such was the writer's fantasy. Still there is a grain of truth in it.

A. Tolstoy wrote his remarkable novel more than thirty years ago. But even before that, in 1909, the Yugoslav scientist A. Mohorovicic recognized a specific layer in the interior of our planet on the basis of seismograms. At its boundary underground earthquake waves increase their velocity as they travel through the deep-seated strata. This boundary is known to researchers as the *Mohorovicic discontinuity* or *Moho.* Everything above it is the Earth's crust. All that lies below it is still a riddle: this is where the Earth's mysterious mantle begins.

The solid crust has been studied for many years. Thousands of prospectors have carried out and continue to carry out geological surveys. In digging shafts and drilling through rocks, men have always collected samples of various rocks. These samples are then compared and the depth at which they were found is recorded. Thus was accumulated information on the structure and composition of the Earth's crust. In our days engineers have come to the aid of naturalists. Nowadays geologists are aided everywhere by machines and sensitive instruments.

It is known now that the solid crust of the Earth consists of two main layers. The upper one is conventionally called the granite, and the lower one, the basaltic layer. Granite is a rock everybody knows. Basalt is a dark, very compact rock consisting of fine grains. It is thought that in the distant past granite was on top, having floated, as it were, to the surface of the heavier basalt. The solid body of the Earth may possess certain liquid properties. It may shift heavier particles inside itself towards the centre, and lighter ones, to the surface. Reasoning in this way, it may be concluded that the heavier metals are possibly stored away deeper in the interior of our planet. And so, it turns out that Tolstoy was not just imagining, but made ample allowance for the achievements of science.

Now the time has come to really have a look below the mysterious Mohorovicic discontinuity. Man has created an artificial planet, which has flown millions of kilometres into outer space. But the prospector's drill has penetrated only six or eight kilometres into the Earth's crust. Millions of kilometres and less than ten kilometres! How little we know as yet about the interior of our own planet!

At first the idea was to sink a special shaft, slightly resembling that on the fantastic Gold Island. An abyssal lift was to be let down it. But where should this shaft be dug? On dry land the Earth's crust is very thick. Just try to go tens of kilometres down into the scorching heat of the Earth's interior! Azerbaijanian scientists say that only ten kilometres down the temperature will be as high as 400°C. And the pressure there is the same as under a forge hammer. Well, they probably know more about this than anybody else; there is hardly a place in the world where the earth has been drilled more than in oil-bearing regions. So researchers turned their eyes hopefully to the ocean expanses. Certainly, here is where it would be easiest to reach the boundaries of the mysterious Moho.

And so in 1961 near the island of Guadeloupe in the Pacific Ocean, there appeared a large raft carrying a drilling unit. Beneath the raft lay almost 3.5 kilometres of the blue strata. American scientists assumed that under it lay a few hundred metres of loose sediments, after which began the mysterious mantle.

Their assumptions turned out to be right. Only 150 metres of sediment separated the ocean floor from very dense rocks. The hole was sunk to a depth of 36 metres, but after this the work had to be discontinued. Underwater drilling from a raft proved to be too difficult. It was impossible to get the drill back into the hole.

All that remained in the hands of the geologists was a black stone with glistening faces of tiny greenish crystals. It was a sample of abyssal "basalt", born in the boiling hot cauldron of volcanic eruptions. Its name is derived from the Ethiopian word "basalt", meaning boiled. Perhaps this sample holds the key to the mystery of the mantle? Many scientists investigated pieces of the sample very carefully, but could say nothing new.

Soviet scientists are also undertaking an attack on the Earth's interior. They have decided to drill on dry land, rather than in the sea.

But where? Wherever the hard basement rocks crop out on to the surface. The hole walls will then be strong enough to make casing unnecessary. Deeper down, at the beginning of the seventh kilometre, evidently come the so-called basalts. They are also strong, and hence a hole 15 kilometres deep can quite possibly be drilled in the ground.

What to drill with? This can be done with a laser ray resembling Garin's death ray, or with a jet-piercing or turbine drill, which is more probable.

But already voices are heard questioning: "Is it worth while?"

FACTS FOR THOUGHT

It was all routine work. An expedition on the scientific ship "Vityaz" was working in the central area of the Indian Ocean. Above the ocean floor rose the invisible Mid-Indian Ridge.

The researchers carried out geophysical measurements. Then they lowered a drag to collect floor material in the region of a submarine fissure in the Earth's crust. Some time later they hoisted the drag on deck and saw curious fragments of rocks with chromite concretions. They were close in composition to the supposed matter of the upper mantle.

That was in 1965.

The find especially delighted Academician A. Vinogradov. It was a practical confirmation of his new theory of the origin of continents and oceans.

Many scientists still believe that the hard crust of the Earth formed as the latter cooled down. In this process heavy matter sank and light substances floated, as it were. The water of the oceans fell out of the atmosphere. At first it was fresh water. Later the rivers washing the salt out of the land, gave the sea water its bitter-salty taste. Everything seemed quite consistent.

But then it was decided to perform experiments.

A fragment of protoearth, a messenger from outer space, was brought to the laboratory. According to the opinion of many scientists, the Earth was originally a cold clot of rock accumulated from cosmos matter. Only afterwards did it begin to warm up, and even then not at all points. The fragment of meteoritic matter was fashioned into a cylinder, a small model of a new-born planet. Then it was heated and melted under high pressure in a special apparatus. First one part of it was melted and then the melting zone was gradually shifted. Together with this zone all the easily fusible materials passed over to the other half of the model. Only refractory materials remained in the refrozen part. Simultaneously, gases were liberated.

A similar kind of zone melting of rocks evidently occurred in the upper mantle of the Earth. It separated the refractory from the fusible substances, but the former were not necessarily heavier than the latter.

During this zone melting gases and water, saturated in salt, were liberated. Hence, the oceans were salty from the very start. Hence, the continents squeezed water out of themselves, as it were, leaving "dry" basalt. The "firewood" for the boiling cauldron of the Earth's interior was the radioactive elements.

These conclusions are also logical. Experiments support this new hypothesis advanced by a well known Soviet geochemist. But there still is a "but"... Radioactive minerals are found mainly in the not very deep strata.

But what about the very deep strata? This is still a riddle. Heat is evolved by the long-lived isotopes of uranium, thorium, potassium, etc. Their half-lives are comparable with the age of the Earth. If our planet is at least 5 thousand million years old, it should have evolved almost 1.5 times more heat than if its age were 4.5 thousand million years. The Earth's "furnace" would be the same, but the amount of "firewood" would be entirely different. Again a riddle.

The short-lived isotopes of aluminium, beryllium, iron, chlorine, etc., also create heat. Their half-lives are only a few million years. If all the energy of these radioactive elements stayed inside our planet, do you know what would happen? Its temperature would rise to 3000°C. One more riddle for scientists.

And what if the Earth's-family-tree experts Fesenkov and Verkhugen are right? They calculated that during the formation of protoearth from cosmic particles the energy of gravitation alone could evolve an immense amount of heat—quite enough to turn our planet into a white-hot gas.

But the Earth did not evaporate in the past, and it is still fairly cool. Here are facts for thought.

The Earth's solid crust is about 40 kilometres thick under the continents, and averages 6 kilometres beneath the oceans. Below it is the surface of the mysterious mantle. At such depths the velocities of propagation of seismic waves increase in all parts of the planet's shell.

Scientists studied the seismic properties of identical rocks at different hydrostatic pressures and found that the velocity of elastic waves increases with increasing pressure. Hence it may be thought that in the Earth's interior substances differ in physical state rather than in composition. But if this is so, is it worthwhile looking for specific rocks in the mantle?

Everybody knows that the density of ordinary quartz is 2.6. Not long ago the Soviet scientists S. Stishov and S. Popova made an artificial variety of quartz of density 4.35. It was named stipovite, after the first letters of the scientists' names.

Perhaps this resembles the rocks from the mysterious depths of the planet? The mineral forms under a pressure of 120,000 atmospheres and at a temperature of 1000°C. Are these not facts for thought?

And so it appears that the substances occurring at depths may be of a similar composition to those of the crust, but in a very dense state. But how could the continents "float" then?

Yes, many are the paradoxes of our planet of riddles, the Earth, disguised in a mask of different rocks. A. Vinogradov was right when he said:

"A scientist keeps making mistakes until he finds the truth."

SEEING THE INVISIBLE

In order to find, one must know how to seek, one must foresee the invisible, sense the impending, never lose heart at failures and difficulties, display persistence and work a lot.

D. I. MENDELEYEV

THE SEARCH FOR EXPLORATION METHODS

Academician Fersman's Cave

Nobody even suspected there was a cave at that mine. Nor did Alexander Fersman. He arrived in south Fergana in spring, 1924 and saw a narrow limestone ridge containing valuable ores. They filled cavities which meandered quaintly through the rocks.

There were many questions to be solved. "In what direction should the shaft be sunk? Where are the major reserves of rare metals situated? Is it worthwhile working the deposit any longer?" asked the miners.

The scientist intently studied the section of the limestone ridge with the shaft marked on it. It ended in an unknown area.

What to start with?

First, all the geological data about the mine had to be gone through. But they gave no answer. That much was clear. But maybe something helpful could be found in the dozens of French and German scientific papers about similar cavities dissolved in the limestones of the Karst plateau in Yugoslavia? It is after this plateau that such cavities were named *karst caves.*

Among them are caves resembling in shape the inside of a bell or funnel. There are also caves known as pipes, which may be vertical or angularly jointed and are sometimes several hundred metres long. There are also horizontal passages, either with dead ends or passing into underground rivers. At places these passages communicate with underlying bell-shaped caves. Fersman proceeded from the assumption that the Fergana limestone ridge could hardly differ in this respect from its Karst counterparts. But this had to be proved by facts.

He went down into the mine and saw that the ore tended to fill all the cavities available down to the last rain rill. This made it clear that the ore bodies formed after nature had prepared these cavities as storehouses for them. That was very long ago. This karst was evidently an old one.

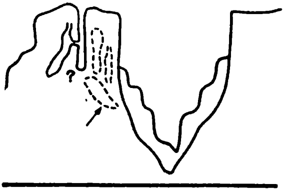
But there were also young, fresh cavities in the localities of the deposit. Therefore they had first of all to be separated from the mature karst. Fersman did not find this difficult. From his student days he knew that a young karst consisted of small fragmentary cavities, whereas a mature karst often consisted of caves with stalactites. They are evidence that the dissolving activity of the water had ended. As a rule, old cavities are located next to water-bearing rock strata. But where are the underground storehouses of rare metals concealed? At what depth?

To clear up the main secret, Fersman did not have to go down into the mine again. He wandered over the slopes of the ridge under the blue sky and the torrid sun. He walked along a cool mountain river which in the course of many centuries had cut itself a canyon 300 metres deep. He looked over the rills on its banks, counted the terrace steps alluviated in the past, measured the heights of the outcrops of spring water and ... established a correlation between them.

The terraces showed that the level of the river cutting into the rock had gone down in jumps. At times these jumps were retarded. Then the underground waters started to do the greatest part of their work. They diligently broke their way through to a stable level, dissolving cavities in the limestones on their way.

The mountain river had four main terraces. The first rose 20 metres above the level of the rushing waters, the second was 40 metres above it, the third, 80 metres, and the fourth, all of 220 metres. But Fersman did not count them from the bottom up. He had decided to "look into" the underground from the surface of the limestone ridge.

The level at which the river flowed before it had created the deep canyon, was the zero level. Then a terrace went down 140 metres, a second 180, and a third, 200 metres. The step from the first ancient terrace to the second was the larg-



Cross section of a limestone ridge, river valley, and karst caves.

est. Hence, inside the range down to a depth of 80 metres falling waters played the main part in that epoch, washing out vertical cavities. Below, as is evident from the younger terraces, there was no deep washout, nor were the underground streams there violent; they calmly dissolved the limestone. They ran along in gently sloping rivulets, creating large caves. This is where, at depths of from 140 to 200 metres, the commercial reserves of valuable ore should be sought. Here the surface of ground waters would be very close. That was the conclusion Fersman came to.

Fersman left the mine. The miners continued their work sinking their shafts deeper and deeper into absolutely dry rock. Some of them even began to laugh at the scientist. And how! To think he could see the invisible from above! There's a rum fellow for you! But when the shaft had gone down to 174.5 metres ground water actually appeared, and the large lower cave predicted by Fersman was also found.

It was named after him.

This made the critics eat their words. The deposit had indeed not come to an end.

Where do Deposits End?

"Almost all the deposits in eastern Transbaikal are concentrated on the southern slopes of the mountains," stated a friend of mine.

He was right, but I did not agree with him. Why? On the southern slopes of the Transbaikal mountains there are many river watersheds, the loose deposits are often washed away, leaving the hard rocks clearly visible. Besides, there are no continuous forests there. But on the northern slopes are frozen overburden, turf, and forests. It would seem, you could never see any useful minerals here.

But is this so? Are there no other indirect signs?

You can tell where a camp fire is burning by the rising puffs of smoke. You can tell where economic minerals are likely to occur by travelling chemical elements. They disappear in some places and accumulate in others. Sometimes they even reach the surface. It is necessary only to find the traces of these invisible elements.

Sometimes they even move in the form of a deposit. Take, for instance, petroleum. It is formed mainly of the chemical elements carbon and hydrogen. In the depths of the Earth's crust the mobile hydrocarbons seek the points of lowest pressure. Gradually the hydrocarbons are squeezed, as it were, into porous sandstones and sometimes into limestones and clayey limestone rocks, dolomites, which they saturate like water saturates a sponge. And where further progress is blocked, they accumulate.

Surrounded by dense, most often clayey rocks, the light hydrocarbons collect mainly in folds of sediments somewhat resembling inverted vessels. At the top of these folds is gas, then comes petroleum, and beneath it, water, which is heavier. All this is a storehouse of "black gold".

If the storehouse vessel has too many cracks, the hydrocarbons will finally disperse along them in the directions of least pressure, and the deposit will spread out or even disappear altogether.

Thus gaseous and liquid minerals can form at one point, accumulate at another, and spread out to a third. But what about solid ones?

Related to natural storehouses of petroleum and gas are mud volcanoes. There are many of these apparently unobtrusive hills in Azerbaijan. From time to time they become active and throw bubbling mud and fragments of plutonic rocks out on to the surface.

At first glance the Koturdag volcano is the same as any other of these. Still, it has features of its own. The volcano keeps erupting solid rock, which is thrown out of the depths by the forces acting in the Earth's interior. Slowly, at a rate of 16 to 18 metres per year, this "solid river" 1.5 kilometres long flows in a northwesterly direction. Its continuous motion is hidden from view, and can be detected only with precise instruments.

Or take, for instance, so-called salt plugs. Many of them are valuable deposits of rock salt. They occur in the northern part of the Caspian basin in the Soviet Union, in the state of Texas, USA, in the north of Central Europe, and in general at different points of the globe. But do you know why they are so closely connected with blue fuel and black gold? Do you know that they move through the Earth's crust like glaciers sliding down a mountain side? Only glaciers creep downwards under the force of gravity, while salt bodies rise slowly to the Earth's surface.

Salts also possess fluidity, though much less than petroleum. They are often lighter than other rocks. For this reason the pressure of the surrounding rocks squeezes them out, like toothpaste from a tube, in the direction of least resistance. In hundreds of millions of years a salt plug may travel thousands of metres through rock strata. It will choose, wherever possible, the same path as that by which hydrocarbons rush to the surface. Probably some of these deposits will themselves in time crop out on to the surface. And then they will become quite noticeable. Noticeable is not difficult to say, but much more difficult to check. Now if you could see with your own eyes on a movie screen.... Do you think that impossible?

Such a film was actually made in Novosibirsk, at the laboratory of experimental ore formation. The film was made in a simple way. A transparent box was divided into parts, the middle was filled with rock, and chemical solutions were poured in between porous partitions around the edges. When these solutions met the rocks, they were to react with them to form ore minerals. The box was sealed and placed under an automatic camera, and that was that.

The first colour film the geologists made, which might have been called "The Search for Invisible Forces," ran for only ten minutes. But what it showed them made them scratch their heads for a long time. And no wonder! The ore zone moved quickly, as if alive, through the rocks. Sometimes it would stop and "pounce" on the rock grains, changing them to dust and dissolving them. The hard stone could not withstand this and split apart, and ore veins formed in the cracks. It was clearly invisible intermolecular forces that were acting. Hence immense pressures and high temperatures, whose energy we can see, are not all.

And so, where are deposits moving to? Where do they end? Earlier established views can hardly supply answers to these questions.

Provinces of the Interior

They actually have them in the Earth's crust. They are outlined not by the arbitrary signs of geographical and administrative divisions, but according to weight or atomic percentages of natural chemical elements.

These percentages were first calculated in 1889 by the American scientist F. W. Clarke. Many years later A. Fersman suggested the term clark for the average unit of content of chemical elements in the Earth. This suggestion was accepted, and now geologists have a unit of their own for determining the zones of occurrence of invisible minerals.

They are represented by natural chemical elements. The most surprising thing is that they include the universally known gas oxygen. It accounts for 46.4 weight per cent of the Earth's crust. Then why is the crust stony and not airlike? This is simply because oxygen occurs there in chemical compounds, such as silicic acid—ordinary quartz.

Incidentally, there is a great deal of silicon in the Earth too—27.6 per cent. Next comes the source of a very light metal, aluminium—8.1 per cent, and then iron, about 5 per cent. Calcium, sodium, potassium and magnesium are distributed in approximately equal quantities and total about 11 per cent. Other elements include hydrogen, carbon, phosphorus, sulphur, chlorine, fluorine, titanium, manganese, etc. The contents of each of these elements constitute tenths or hundredths of a per cent.

What are known as the trace metals, lithium, tantalum, scandium, radium, and others, have very low clarks and are contained in rocks in very small quantities. That is why geologists understand the words of V. Mayakovsky's verse so well:

Poetry
is the same as radium mining.
To win a gram,
toil a year or more.
You use up
to get the word you're finding
thousands of tons
*of wordy ore.**

Thus, the rocks inside the Earth differ greatly in chemical composition, in clarks. Some rocks are almost two thirds compounds of silicon and oxygen. Such, for instance, are granites, which contain a great deal of quartz, or silicic acid and are for this reason called acidic rocks. Others are about half silicic acid and are known as alkaline or basic formations. Those that contain about 45 per cent of the leading chemical elements of the Earth are called ultrabasic rocks.

If we are looking for potassium it is necessary first of all to reveal the presence of acidic rocks.

* Translation by D. Sobolev.

They contain 1,000 times more of this element than ultrabasic formations. They also contain 100 times more chromium, cobalt, and copper, and 10 times more lithium, rubidium, and cesium. On the basis of these differences Academician A. Fersman suggested in his time that regions of the Earth's crust with a definite and characteristic content of chemical elements should be called geological provinces. That is how the Earth's interior acquired its "administrative" divisions.

And now let us recall the opening words of the previous section. "Almost all the deposits in eastern Transbaikal are concentrated on the southern slopes of the mountains," stated a friend of mine. He was right, but I did not agree with him.

Why?

Because both the southern and the northern slopes of the Transbaikal mountains belong to the same geochemical province. The deposits of this region may still be hidden from man under frost-bound detritus, but the time is probably not far off when they will be discovered.

The Mendeleyev Periodic Table, the Modern Urals, and Past Epochs

Is all this compatible? Let us have a look at Fersman's *Geochemistry for Everyone**. Here are some lines from it: "The Urals appear before us as an enormous Mendeleyev's Periodic Table

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* A. Fersman, *Geochemistry for Everyone*, Foreign Languages Publishing House, Moscow, 1958.

spreading across the rocks. The axis of the range and of the table passes through the heavy green rocks of platinum deposits. Its extreme groups are in the salt zone of famous Solikamsk and in the regions of the Emba.

"Is it not a marvellous confirmation of the profundest and most abstract ideas? I believe you have already guessed that in Mendeleyev's Table the elements are not arranged fortuitiously but according to the similarities of their properties. And the greater the similarities between the elements the closer to each other they are found in the Periodic Table.

"It is the same in nature. The signs showing various minerals on our geological map have not been put there by mere accident, as it is no accident that osmium, irridium, and platinum or antimony and arsenic are encountered in nature together."

Indeed, it is no accident!

If we have a look at, say, a school map of economic minerals, this statement will stand out more vividly. There are no gold deposits worth mentioning in Europe. But the Urals is a gold "kingdom". Kazakhstan and Siberia, especially eastern Siberia, are rich in gold. There is a great deal of it in the American Cordilleras at the Pacific Coast. But as soon as we cross these mountains, we find no more gold-bearing regions right out to the Atlantic Ocean.

And so it appears that regions of definite minerals can be outlined on Earth. Geologists can tell beforehand where to look for gold.

The relationship between the periodic table and the regular distribution of riches in the

Earth's interior can be traced not only in space, but in time too, in the past epochs of development of the Earth's crust.

About 420-600 million years ago deposits of iron and gold were formed in eastern Siberia, Kazakhstan, the Altai and in the Sayan mountains. The same happened in the Urals 230-420 million years ago. The gold of Kolyma and Yakut diamonds formed later, only 100-230 million years ago. And the salts of Kara-Bogaz-Gol, a gulf in the Caspian Sea, are forming in our times, like peat and some other minerals.

With each decade man uses more and more elements of the Periodic Table. In ancient times people were quite satisfied with only 19 elements, in the 18th century they were using 28, in the 19th century, 50, but by the beginning of our century they found 59 insufficient. This calculation was made in 1916 by Academician V. Vernadsky.

Later his disciple A. Fersman noted that in the course of the last century the annual consumption of coal, iron, manganese, nickel, and copper had increased by 50 to 56 times, while that of molybdenum, aluminium, tungsten and manganese had grown 200- to 1,000-fold. During the last three decades more non-ferrous and rare metals were mined than throughout the entire history of mankind.

Facts are eloquent. Almost all the deposits that are easy to find have already been discovered. Now it is necessary to search for mineral deposits concealed at depths. That is why geologists now do not simply prospect, but study the history of development and formation of the

Earth's interior. They learn the chemical composition of various rocks, try to find out when and how they originated, and compile geological maps. On them they outline the boundaries of prospective geochemical provinces and regions where economic minerals may occur. All this is the search for methods of exploring deposits.

INVISIBLE ELEMENTS HIDE IN THE EARTH

Primary Aureole. Secondary Aureole

Deposits also spread "infection". True, this infection is not dangerous; it is even useful to prospectors.

An ore body infects the zone around it, as it were, with chemical elements. This zone may be called the primary aureole. The bedrock around a uranium deposit is infected with uranium elements for hundreds of metres around. Their content considerably exceeds the usual quantity in terms of clarks.

The blinking indicator eye of a radio receiver informs us that we are tuning in to the wave we are looking for. The indicator elements found in bedrocks can also report: "Alert! Valuable ore nearby."

Primary aureoles make it possible to detect, for instance, lead-zinc, tin, tungsten, and other ores of rare and trace metals.

Once the boundaries of the primary aureoles are established it becomes easier to determine the shape and actual location of the hidden deposit. The closer to the ore, the higher will be

Propagation of primary and secondary dispersion halos.

the concentration of the indicator elements. Such a dispersion halo is most frequently created by the ore elements which succeed in "escaping" from their deposits in solutions or gases along fractures in the bedrocks. Even if there is very little of these invisible minerals—thousandths of a per cent, compared to the ore—this is much more than their usual content in gangue rock.

But what if the indigenous formation is concealed beneath detrital deposits? In the long run this is no obstacle. The migratory elements penetrate into the most unexpected places and create additional secondary dispersion halos.

Such halos can be detected only by the most precise methods of investigation and only by taking a large number of samples. Geologists collect millions of samples from secondary dispersion halos. Thousands of laboratories thoroughly analyse these geochemical samples.

How this is done, I learned during my first field practice period when yet a student. I took my field practice in an expedition in the taiga near the White Sea.

Hole One, Hole Two ...

At that time I often used to repeat these words, trudging along after Ivan Dmitrievich. Long-legged, lean of body, he walked with a spright step. Frightened grouse fluttered up before him, and the undergrowth of young spruce bent aside. All I saw was his back. Behind us we left little pits—holes which I dug with an ordinary shovel. I would scoop some earth out of the hole into a bag, write a label, and put it in with the earth. Then I would put the bag in my knapsack and march on again. And so we would traverse dozens of kilometres each day and bring back scores of bags of earth.

Prose and nothing else. Why study the works of prominent scientists, listen to lectures on the latest methods of investigation? Why learn to operate complex instruments? It's all so primitive—a shovel, a bag, a label, and a knapsack.

Ivan Dmitrievich only grinned in answer to the fine words I came out with at halts and at the camp fire in the evening on this subject. "All in good time," he would say. "You can't expect to grasp everything at a moment's notice."

By the end of the summer the whole area of our investigations was pock-marked with little pits. That was my work.

My field practice over, I returned to Leningrad. The bags of earth I had prepared were sent there too. In the laboratory the samples were subjected to spectral analysis. The metals contained in each sample were determined from the spectral lines. It was winter when Ivan Dmitrievich asked me to come and see him at his office.

On his desk lay a small geological map of the region of our investigations. It included everything: the difficult kilometres traversed, the weight of the knapsack and the bags of earth, and the addresses of the holes marked on the labels. This map contained the main result of my prosaic work. For the first time I saw not a study picture, but the boundaries of an actual dispersion halo of chemical elements. As if X-rayed, the outlines of an ore deposit showed through it. The outlines of a deposit which was impossible to notice out there in the taiga.

Afterwards I learned that by such metallometric prospecting other geologists had detected dozens of deposits of polymetallic ores in central Kazakhstan alone, and hundreds of finds in the Transbaikal and in the Far East, at places where conventional prospecting methods sometimes gave no positive results.

A simple hole.... You cannot expect to grasp its meaning at a moment's notice.

What Is a Bottle of Water Worth?

Perhaps it would be best to ask a prospector? He bends down over a creek, fills a bottle carefully with pure water, stoppers it up and puts it away in his knapsack. If you think he intends to drink it when he gets thirsty where there is no water to be had, you are mistaken.

Even in a sizzling desert a real geologist would refrain from drinking this refreshing liquid. It might be worth millions of rubles. So much for a simple bottle of water? That seems fantastic!

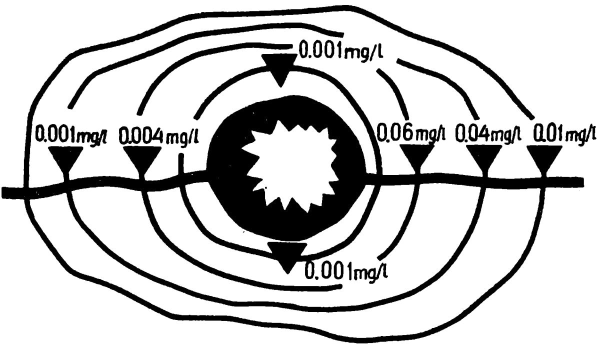
Well then, let us follow the man with empty bottles still jingling in his knapsack. He will help us to understand. He knows how and where rivulets and creeks flow. He knows that there are also waters rushing through the dark interior of the earth underfoot, seeking their way out on to the surface. Washing through stony cracks they carry off with them molecules and ions of chemical elements, of those that constitute underground rocks.

No geologist takes samples from large rivers. Too many small rivulets and creeks have come together in it from all directions, and each of them has brought with it its own "tell-tale messengers". A prospector prefers small, hardly noticeable sources.

The geologist's address book is a map, and his guide, a compass. He collects not one or two, but a great number of water samples. And he must not forget where he took each of them. Then the vessels must be very well stoppered to keep extraneous impurities from getting in, and must be sent off to a hydrochemical laboratory, where one of the mightiest sciences reigns.

Only in the hydrochemical laboratory is it permitted to open the bottles containing this water. It is first subjected to a qualitative analysis to find out what elements it contains. Then a quantitative analysis is performed to determine how much of each chemical compound there is in the solution.

The data of these analyses are recorded on a map and the points at which the samples taken contained equal amounts of the metal of interest are connected with lines. They gradually close in and the outline of the scattering aureole of chemical elements of which the mineral sought is composed becomes more and more distinct. And finally we have a "portrait" of the invisible deposit, like the one the geologists "saw"



"Portrait" of an invisible deposit as seen by means of hydrochemical prospecting.

as a result of hydrochemical prospecting in Central Kazakhstan.

Chemistry is a great help to prospectors. Even the famous prospector's hammer can sometimes be dispensed with. But the heavy knapsack must always be on one's back. It always took a long time to get the results of an investigation.

But could not the prospector's work be made easier and more efficient?

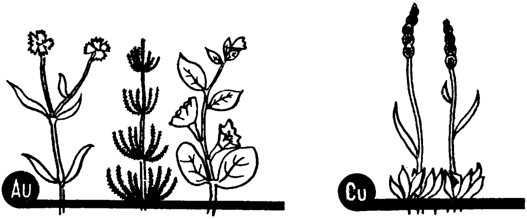
"It can," answered the scientists. And instead of numerous bottles the prospector was supplied with a small bottle of a liquid called diphenylthiocarbazone. The name is very complicated and long, of course, but the liquid makes the determination much faster and so this kind of analysis is called fast analysis. You add the organic reagent to the vessel of water and the water becomes coloured. The hue shows which chemical elements are dissolved in the water. And the hydrochemical map can be compiled right "in the field".

Chemists have made a large number of special reagents for geologists, so large a number that it is difficult even to enumerate them all.

Again the prospectors set out along well beaten paths, and by means of hydrogeochemical methods they discover invisible treasures where nothing was found before.

Leaves and Twigs

This is not a talk on botany. The indefatigable hunter for the invisible collects yellowing leaves in autumn. In the fall he wanders through field and forest. Note that he does this in autumn.



Plant indicators of minerals.

Can it not be done in other seasons? It can, but....

You know, of course, that plants are nourished by solutions of various salts. Their roots are virtually pumps which draw nutritious substances from the ground. Among these substances are oxygen, nitrogen, iron, calcium, sulphur, potassium, magnesium, hydrogen, carbon, and phosphorus.

Trees and flowers grow in different places and are nourished by different media. This means that together with the usual chemical elements they also accumulate others, peculiar to the rocks of a definite locality, though these rocks may be many metres below the surface.

Comes autumn, the time of complete maturity of the green world. That is when the geologist arrives and begins to "select enriched samples". (The largest amount of mineral salts accumulates in plants by autumn.) The twigs and leaves are burnt, not on camp fires, but in special electric furnaces. The ash is then tested thoroughly for chemical elements. The results are compared with the traditional "background" salt composition. If the plant roots go down as far as the zone of ore scattering, the content of metal inherent in the deep-seated deposit in the ash will rise sharply, and this is a real find!

There are also trees, weeds, and flowers, which by their colour or shape indicate underground treasures directly. For instance, a Californian emoltia with grey flowers signals: "Look, there is copper under me." Elsewhere it might be lemon-yellow, and that would mean there is zinc under it. Even modest violets and pansies become remarkably unlike themselves over certain deposits.

Where gold is concealed, the dainty honeysuckle likes to grow. It is a gold lover. Milk vetch bushes decorated with white-pink flowers have special reason to be proud. They indicate where atomic fuel—uranium—lies in the earth.

Milk vetch also points to secluded places where a most valuable raw material--selenium—occurs. Just now hardly 1,000 tons of it is mined per year throughout the world. Selenium is being sought intensively, and is sometimes found in very curious ways.

During a drought in the south of the United States the farmers drove their herds to the far-off prairies. All around were sun-scorched plains. But suddenly one of the herds came across a green glade richly overgrown with milk vetch. The animals fell hungrily to eating the plant and together with it swallowed a large amount of poisonous selenium. Thus, at the expense of a whole herd was discovered a selenium deposit.

But plants do not always benefit from the chemical elements they take up.

Where there is a lot of boron in the soil the prairie weed wormwood, summer cypress and saltwort grow smaller and degenerate.

Imagine a geologist walking over a smooth sunbaked prairie. Where to take samples of rocks? Ground underfoot, and the only sounds around are the whispering of the spear grass and sheep's fescue. But suddenly among them he sees a shaggy goldilocks nodding its downy head at him, as if to say: "Look! See how ugly and small I am. That is because I have drawn too much nickel from the soil—ten times more than usual. Do not pass me by. Look!"

Be on the alert if you see a galmei violet. If it is growing in the locality of a zinc deposit, the ash of the flower will contain as much as seventeen per cent of this metal. Silver birch is also fond of zinc. Mountain balsam shows an inclination towards molybdenum.

The bright green spots usually found on the chalk plant when it grows on abandoned copper ore dumps, suggested that they might be useful to prospectors. Indeed, they have helped to find major copper deposits in the Altai mountains.

The pasque-flower prefers localities where nickel is concealed. Here snowdrops even change their shape. Commercial deposits of nickel were found as far back as 1941 in the north of Finland by biogeochemical and geobotanic prospecting.

Sometimes plants resort to cunning, as it were. In the presence of copper ores containing molybdenum, some of them accumulate 10 to 20 times more of the latter than in blank localities. At the same time, the amount of copper in these plants is only 2 or 3 times higher. In this way it is possible through molybdenum to detect another metal.

Thus, twigs and flowers, which at first glance have no relation to geology, help to find economic minerals.

Invisible Seeks Invisible

It cannot be held in the hand. It cannot be felt like a stone or the ground. It is everywhere, but no one ever sees it. Now do you think such an omnipresent, invisible substance can be used in prospecting?

What is it we are talking about? About air, of course. Air can penetrate any pores, and is mainly a constant mixture of gases. It must be emphasized that the mixture is constant.

"Then everything is quite clear," petroleum workers will say, "it can indeed be used for this purpose." And they will recall hydrocarbons, which are evolved from the Earth's interior in localities where there are accumulations of fuel gases and petroleum.

But we mean prospecting for rare and trace metals. These, as we know, are nonvolatile. All of them? Take, for instance, mercury. It evolves mercury vapours. Hence, it can be sought with a special instrument called an analyzer. And what about the radioactive elements? Are there not gases among their decay products? Wherever there is commercial uranium, the air enclosed in the rocks contains a fairly large amount of helium and radon. Thorium also produces gaseous thoron. These gases are very sly, invisible substances. Only highly perfect trap-type devices can catch them.

Microorganisms are also invisible. Some of them are very fond of propane gas, which is one of the gases contained in petroleum hydrocarbons. On their way to the surface the latter may pass through water-bearing strata. And if a geologist discovers propane-oxidizing bacteria in subsoil waters, he knows that there must be strong evolutions of petroleum gases somewhere nearby.

Prospectors found a great deal of such bacteria in the areas of western Siberia and the Irkutsk Region. These bacteria have also taken up their residence in the oil-bearing regions of the North Caucasus. Besides, the richer the "black gold" deposits, the more of these invisible hydrocarbon-seeking inhabitants there will be in the ground waters.

These tiny invisible substances and creatures—signs of the presence of deposits—are imperceptible to the human eye, and it has therefore been necessary to devise very precise methods of investigation. It is sometimes difficult to get a good look at a giant too. Man is but a grain of sand compared to a mountain range or a valley. But in this case too man has proved stronger than nature. Remember the saying: big things are better seen from afar.

ON THE EARTH, IN THE AIR, AND AT SEA

Photographing from an Airplane

"Airplane mapping and aerial photography are being used more and more extensively each year in geological and geographical surveys and are becoming very important methods for both research and practice." This statement was published in the Soviet journal "Priroda" (Nature). When, do you think?

"Just recently," many would probably answer. "Airplane mapping is a comparatively new method, especially in geology."

Quite right. And still the above lines were published in March, 1930. They were written by the great dreamer Academician A. Fersman.

It took more than one decade since then for aerial photogeology to actually become a tangible aid to prospectors. It used to be said that the geologist depended upon his legs for a living. Now we may add that he also depends upon the airplane. Air-borne survey is especially valuable for geologic mapping. True, the aerial prospector has to be a geographer, a geobotanist, a geophysicist, and a mathematician, all in one.

He must be a geographer to be familiar with landscapes. He must know botany to be able to distinguish between different kinds of flora, for to them are related definite species of rocks. Well, and a knowledge of physics and the ability to carry out mathematical calculations are needed to avoid having to work "by eye", as they say.

Have you heard of spectrozonal photographic films? They have helped to extend the range of human vision. Such films are especially good for territories with intensive vegetation. These places are often associated with detrital areas and outcrops of wet strata. Such things have a meaning to the geologist.

There is an amusing "toy" called a stereoscope. You look into it and instead of two flat photographs you see a single volume image. The same principle is used for aerial stereosurvey. There are times when you keep measuring and measuring, with the aid of a compass, the directions and inclinations of beds on the ground and then you look at a stereophotograph and see that you have been doing it all in vain. Either you have measured an immense boulder which slid down a mountain side, or you have done some other unnecessary work, such as determining the fine corrugations of a layer. (There are such things in nature, something like a slated roof.) And you find that all the measurements could have been made much more simply and accurately from photographs.

Recently rather unusual methods of survey have come into use in geology—radar survey. By means of reflected radio waves the image of the Earth's surface is changed into a photograph. Such "photographs" reveal water, as well as ores concealed in the rocks. Radio waves penetrate the Earth's crust to a certain depth. However, this is mainly the future of aerial photogeology. Today the geologist can readily discern folds, faults, and fracture zones even on ordinary photographs, can delineate from photographs areas of deposits in river valleys, and see where the clastic material from eroded rocks has been spread.

The aerial photogeologist has to plan his work in various geographical regions by the hour, day, and month. Prospecting over a valley is best done in the morning. Slanting solar rays accentuate fine relief features. The best time for surveys over mountains is mid-day. Then gorges can be seen very well and there are less shaded areas. If a spectrozonal survey of a semi-desert terrain is to be carried out, better wait for spring. In humid regions aerial photography is best conducted in autumn when the trees have lost their foliage.

From above the photographic eye can see a great deal on the surface of our planet, that helps to decipher the secrets of its interior. A great deal can also be seen by just walking along the ground. It is only necessary to observe carefully all the highlands and the lowlands, lakes, rivers and other objects of the so well known relief.

Peaks, Depressions, and Rivers

One rainy evening in Leningrad I sat in a library looking through the geological works of M. Lomonosov, when I came across an utterance which has direct bearing on modern methods of mineral prospecting, based essentially on studying the shapes of the surrounding relief.

Lomonosov wrote: "The very place where veins occur can be recognized by the following indications: if a ravine or furrow lies on a mountain in a place where water cannot be supposed to have washed it out, look there to see whether the mountain itself shows no general signs of the ores it contains in its interior."

What brought Lomonosov to this conclusion? Experience or researcher's intuition? Or maybe these lines were written after reading the report of Ivan Sarmanov, a minor official of the Siberia Department, about a mountain he had examined on the Tagil River, which had a "magnetic hillock about a sazhen high?"

This mountain caused a great deal of trouble to Urals officials. In 1696 they received a letter from the Tsar which read: "It has become known to his Majesty that there is lodestone—iron ore—in the Verkhotur District, and though this lodestone has been seen in many places, none of it has come into the possession of the Siberian Department."

Sent forthwith to the spot the army foreman Fyodor Nakoryakov broke off three poods (about 100 pounds) of ore. But at that time there was nobody in the Urals who could smelt it. The ore was delivered to Moscow, where it was tested in the Armoury and found to be "harder than Swedish, but can be used for any purpose". Then the lodestone was sent on to Riga to Johann Miller, metallurgist, and thence to Amsterdam to the Dutch master Andrew Thallus. Everywhere the iron from the Urals mountain was praised highly. In Soviet times the Magnitogorsk Iron and Steel Works grew up here.

There was no difficulty in finding this deposit. The hill displayed itself.

Individual hills stand out on the plains of Central Kazakhstan, too. At first sight they seem to be just ordinary hills. But if examined carefully they are often found to consist of dense quartzite rocks. Among them occur the copper ores of Kounrad.

In eastern Siberia the strong seams of the Angara-Pit Iron Ore Basin crop out in a chain of hills.

And in Azerbaijan there are about 200 hills shaped like truncated cones. These are mud volcanoes. The most interesting thing about them is that they give oil and gas prospectors information from depths of from 10 to 12 kilometres.

D. Golubyatnikov, a renowned geologist, once said that mud volcanoes serve as singular kinds of prospecting wells. Fashioned by nature they deliver to the Earth's surface samples of deep-seated oil-bearing rocks. Rises in terrain are often due to humping of the Earth's strata into a sort of dome. This makes an excellent reservoir for oil and gas. More than half of the gas and oil deposits in the USA, for instance, are concealed beneath such dome-like hills.

The surface of our planet also has many depressions. Of course, sedimentary minerals such as bauxites, salts, and coal should be sought in localities which are, or formerly were, depressions.

Dark coloured soil and rodents' burrows on the surface are characteristic of loose coal-bearing deposits. Even night frosts in autumn may be of help to geologists. They disappear first at outcrops of coal seams.

The prospector takes note not only of modern relief. He also "sees" the relief of bygone epochs. He sees the former surface of the Earth, now overlain by rock strata.

There would not seem to be much use in knowing where a river bed passed previously. But it was just in such a bed that as far back as 1910 the prominent scientist I. M. Gubkin discovered an oil deposit. It had selected quite a suitable dwelling with walls of compact river-bank rocks. Petroleum has also settled where waters ran previously in the district of Ishimbai and Chusevskiye Gorodki in this country and in eastern Kansas and Oklahoma in the USA.

By studying the wanderings of these former rivers attentively, the direction in which the ancient relief of the Earth moved can be ascertained. Water flows from areas of higher elevation to those of lower elevation by gravity. Therefore rivers are natural tools for determining gravitational forces.

Geologists have long sought invisible treasures by calculating the changes in gravity forces on the Earth's surface. Not by studying the valleys of modern and ancient rivers, but with the aid of special, very sensitive instruments.

Gravitas—Weight

Professor Galileo behaved like a naughty boy. He climbed the famous leaning tower in his native town of Pisa. He took up with him balls of various weights and let them fall simultaneously, and was glad to find that they arrived at the ground also simultaneously. But this outraged the scientific scholars of the local university. Childish nonsense! It had been known for ages that light things fall slower than heavy ones, and there was no point whatsoever in discovering new laws in this connection. That was more than three hundred years ago, when Galileo first succeeded in calculating the acceleration due to gravity. His reasoning was simple. At the moment a body begins to fall it is motionless; in other words, its velocity is zero. After one second the velocity is equal to the acceleration, and then continues to increase each second by the value of the acceleration. The latter is what had to be determined. But how? One way would be to drop weights from a tower.

It was this "mischief" that started the science of gravimetry. It is now used to study variations in the acceleration of gravity at different points of our planet.

For a long time scientists were unable to think up a good name for the unit of measurement of this force. Only in 1930 did the International Congress at Stockholm name it gal, in honour of Galileo. One thousandth of this unit came to be known as a milligal. That is the accuracy to which various rock densities are determined; you will recall that weight and density are interrelated concepts.

There are various designs of gravimeters nowadays: spring-type, pendulum-type, and quartz-type; but their purpose is all the same—namely, to see the invisible.

Very sensitive instruments now exist. Among them are devices resembling the Cavendish torsion balance. The main part of these is a wire with a beam suspended from it. The wire is a special one, made, for instance, of tungsten, so it should "pay no attention" to such extraneous influences as a drop of temperature. The beam is made of a nonmagnetic material, to eliminate the influence of magnetic attraction. Besides, gilded lead balls are suspended at different heights from the ends of the beam. The apparatus is enclosed in a heat insulating case to shield it from external effects. It has an optical system and a photographic recorder which registers the vibrations of the beam due to changes in acceleration of gravity. These vibrations are greater for compact rocks than for loose ones. And this makes it possible to determine where rocks of unequal density lie in the interior.

The first to try this at the turn of our century was the Hungarian scientist Eötvös. The same was repeated by Soviet geologists after the Revolution, when they decided, on V. I. Lenin's instructions, to tackle the riddle of the Kursk anomaly. And then... you have of course heard of the Ukrainian iron deposits in the Krivoi Rog basin, but you will hardly have heard that the true wealth of this region was determined by means of gravimetric survey. Ferruginous quartzites in this locality reach down to a depth of up to 4 kilometres.

In 1959 geologists walked over the frozen Angara. What, it would seem, could they see under the thick armour of ice, under the rushing waters of the Siberian river. But gravimetry showed that there was a deposit there of lead, much needed by the Soviet industry. In the area of the Kuibyshev dam gravity prospectors discovered and studied the ancient valley of the Volga, buried under other sediments. There is no end to such examples.

On the basis of a large number of measurements geologists compile a map of gravity anomalies. The complex calculations can be made by electronic computers.

Underground mountains and rock masses hidden among the sediments of seas of bygone epochs cannot be seen. But on maps of gravity field anomalies compiled from gravimetric survey data we can see where the deep-seated boundary between crumpled and intact strata passes, where there are major folds of sedimentary rocks, in which gas and oil are fond of settling. Of course, this requires a great deal of care and attention. Very often rocks of different densities occur side by side in the Earth's interior, and folds may differ in shape and size. Major overlying folds may repeat the features of more ancient underlying ones. Of course, the gravity field will reflect a semblance of the predominating irregularities. In such a way petroleum-prospective underground structures may be camouflaged by empty ones. However, such difficulties cannot daunt Soviet geologists, who often undertake to solve more difficult problems. What fluid is concealed in the depths, petroleum or water, or maybe gas? Since these substances have different densities, such questions can be answered without drilling.

A Tempting Idea, but ...

In fall, 1959, an aircraft took off from the American military air base at Edwards, California, with an instrument on board for studying gravity anomalies.

The flight was unsuccessful, because the instrument was too good, its precision being too high. The instrument registered not so much the fluctuations in acceleration of gravity, as changes in acceleration of the aircraft. The only difference between these two accelerations is that the former is independent of time while the latter is. An upwards or downwards shift of the aircraft of only 60 centimetres per second would give a 300 milligal acceleration of gravity, making it quite impossible to notice anything else, because gravitation anomalies of minerals are much smaller in value.

One way out of these difficulties would be to make the aircraft fly uniformly in a straight line. Then the acceleration of its motion would be zero. But this is practically very difficult to do, and it is probably easier to make a coarser instrument insensitive to rapid changes in speed and altitude.

But then how could allowance be made for changes occurring over long periods of flight time? How could other interferences be measured precisely enough? Such interferences are caused primarily by the centrifugal force of the Earth's rotation. When the aircraft carrying the gravimeter flies eastward, the centrifugal effect increases and the measured force of gravity decreases. And as soon as the pilot turns his plane in the opposite direction the reverse occurs.

Secondly, the curvature of the Earth's surface does its part. Aerial prospectors must take into account changes in the force of gravity due to this factor too. For this reason looking for deposits by this method had to be abandoned for the time being. It could be used only for general, approximate gravimetric survey of the Earth's surface. A new jet plane, dubbed "Miss Milligal" by American researchers was first employed for this purpose in 1963.

But thousands of prospectors continue the search for economic minerals on the ground as before. They have solid ground underfoot. It is calm and therefore offers little interference to precise measurements of the minutest fluctuations of thousandths of a gal.

Gravity prospecting is one of the leading geophysical methods. Still it is preceded by the most troublesome and noisiest method of exploration.

Reflection and Refraction Methods

A bottle of mercury, a telescope, and gunpowder helped to lay the foundations of seismic prospecting. In 1851 R. Mallet exploded a charge of gunpowder and through a telescope observed the disturbances caused by it on a mercury surface. Thirty-seven years later I. Schmidt studied his experiment and came to the conclusion that curves could be plotted representing the dependence of the travel time of elastic waves on the distance between the point of explosion and the point at which the receiver is located. Such curves have become known as "hodographs", a word which may be translated as meaning "path recordings". Hodographs, or travel time curves as they are often called, make it possible to see how the rock layers lie in the dark interior of the Earth.

Bang! Travelling in all directions, the elastic waves generated by the explosion also run downwards into the Earth's rock strata. The waves are reflected and refracted at the boundaries between these strata and return to the surface.

The reflected waves are then studied by the so-called reflection shooting.

If you know how the ocean depths are measured with echo sounders, or distances by radar, it is hardly necessary to explain the reflection method. The rate of propagation of elastic waves through different rocks is known beforehand. The time they take to travel there and back can readily be measured. Hence, it is easy to calculate the distance to the layer from which the wave was reflected.

Of course, things are a bit more complicated in actual seismic prospecting. Rocks may occur very nonuniformly in the depths, like in a badly baked layer cake. For this reason prospectors do not confine themselves to a single detector but record the waves simultaneously at several points and find what they are looking for by comparing records.

Another most important method of seismic prospecting is the refraction shooting. The Earth's layers reflect waves at different angles, and some waves may be reflected at right angles, turning into grazing waves, which run along the surface of the layer. Tripping, as it were, over the rough spots of the latter, it is refracted and then returns to the surface, where it is caught by seismic transducers. This happens in strata where the rate of propagation of the waves is higher than in the overlying rocks, in strata of denser substances. For example, it may occur at the boundary of magmatic formations buried under loose sediments.

The refraction method is used mainly for studying the relief of the solid underground basement and the depth of its occurrence. The reflection method is more suitable when it is necessary to find out whether there are any folds in a thickness of sedimentary rocks. It is here that petroleum is mostly found. That is why more than half, and sometimes almost all of the prospecting for oil structures is done by the reflection shooting.

Soviet scientists have developed other methods too. One of them is known as the correlation refraction method (CRM), and another as deep seismic shooting (DSS). The CRM makes it possible to compare not only once refracted waves, but also waves that have been refracted twice or more. The second method is employed for studying the entire thickness of the Earth's crust.

Details of Progress

Here are two facts. Only the pendulum of the first Wiechert instrument made last century for picking up seismic vibrations weighed 10 tons. A modern seismic transducer weighs from 60 to 100 grams. The difference, as you see, is about one hundred thousand times.

A moving sensitized paper tape as the canvas, and a beam of light on it as the artist's brush. What could be better, one might think, for drawing the traces of seismic waves? But afterwards the tape recorder was invented, making it possible to preserve signals from the Earth's interior like the beautiful strains of Strauss' waltzes. Another detail of progress.

Gunpowder has long served as a source of concussion. Nothing could hardly be found to replace it. But researchers took a new path, and invented, first, a combined unit, a plate with a detonating fuse. A light explosion, and the plate moves instantly downwards, striking the ground and sending vibrations into the interior.

Then they mounted on a cross-country vehicle an electric vibrator which could produce waves of definite frequency. Though they return from the interior while the vibrator itself is still operating, this chaos in recording causes no difficulties. Another instrument, called a correlator, has been invented to separate the signals sent by the vibrator from the waves returning from the interior.

Seismic prospectors have learnt to use new very complicated instruments. But when necessary they do not forget the simplest one, the good old sledge hammer. It helps to look into the not very deep interior, but the vibrations produced by it are picked up by a very sensitive instrument, the oscillograph.

Vibrations of the Earth's surface can be felt only on the Earth. True as this statement may be, it does not keep seismic prospectors from going up into the air. They let a receiver down

A simple sledge hammer can help seismic prospectors look into the depths of the Earth.

from one helicopter and a source of vibrations from another. This is an especially convenient method of studying underwater strata.

It was here more than anywhere else that researchers came to understand it was high time to give up using strong explosions. On account of them thousands of hundredweight of killed fish are thrown out annually on to the shores of the Caspian Sea. And there is a good alternative. Instead of dynamite a capped tube with a spark plug inside is lowered into the water. Oxygen and propane gas are delivered to the tube and the mixture is exploded by an electric spark. The resulting pressure jump in the water is smaller than from an explosion and causes no harm to valuable fish and mollusks.

In general, water-borne seismic prospecting has many curious features.

The Path to Piezocrystals

This path started among the lakes and swamps of the American state of Louisiana. Forty odd years ago, in 1927, boats carrying infringers of the peace appeared there. From some of the boats seismic detectors were let down into the slime on the bottom and from others dynamite was thrown into it. Explosions burst out here and there. The infringers of the peace recorded the results of their activities on maps and geological sections and found that at a depth of 1.5 to 6 metres there lay several salt domes, signs of the presence of oil-bearing formations.

Then the seismic prospectors left their boats and went on boardship. They now lowered their seismic receivers to the sea floor at depths of 50, 100, and 150 metres. As to the rest, it was the same as before, with the only difference that they had to spend a lot of time disentangling numerous cables and anchor chains. Waves, sea currents and various other things hindered their work, and for this reason their achievements were rather modest.

Then came the World War II. Hitlerite hordes overran most of Europe and invaded the Soviet Union. The defence effort required a great deal of war machinery, and this machinery needed fuel.

And so at the most difficult period for the USSR, seismic prospectors appeared on the Caspian Sea. Explosion followed explosion—these were probably the only peaceful explosions of 1942. Thus, though ten years late, Soviet waterborne seismic prospecting came into being.

In other seas, ships were being blown up and sunk in those days. Elsewhere deadly submarines hid in the waters, and men anxiously searched the dark sea depths for these swift cigar-shaped boats.

It must be said that this was easier than finding "black gold" in the sea at that time. The Navy had at its disposal hydrophones or submarine detectors to listen in to artificial sounds under the water. Couldn't such instruments be used for prospecting for petroleum at sea? It was found that they could.

The best hydrophone was the piezoelectric crystal type. It picked up seismic waves very well and was not very sensitive to mechanical vibrations. This made it possible not to let the transducer down to the solid floor, but to leave it hanging freely in the water, which meant that prospecting could be done with the ship in motion, and there would be no rope or anchors to disentangle. Was this not what seismic prospectors had been dreaming of?

Besides, a water-borne seismic piezoelectric transducer can now be made the size of a thimble or a matchbox. It consists of, say, a dozen plates of Rochelle salt connected in parallel with an electric conductor to transmit the variable piezoelectric pulses caused by the different external pressures acting on the plates. Their working faces lie against elastic membranes, which, like ears, catch the seismic vibrations penetrating both the solid underwater strata and the water. The instrument is enclosed in a watertight housing filled with oil to protect it from moisture.

Piezoelectric crystals have opened up a new road for water-borne seismic prospecting, but there are still many annoying stumbling blocks on this road.

Water Is not Air

This is self-evident. But if air is surrounded by walls it will help to understand the reason for sea reverberation. The latter resembles the echo which can be heard in an ancient cathedral or a large hall, the aftersound resulting from repeated reflection of sound from the building walls and other obstacles.

Probably, seismic reverberation at sea is the repeated reflection of vibrations from the sea floor and the surface of the water. This idea was first suggested by the famous seismologist G. Gamburtsev. He decided to put his hypothesis to test. He knew that the reverberation at any definite point of the sea should decrease greatly in one second. Actually, however, it faded more slowly than he had expected.

This error did not daunt the researcher. He suggested a new hypothesis, in which he made allowance for the different densities of water, for its saltiness, and even for accumulation of living organisms. However, when tested this new hypothesis was also found lacking. And the question of why these strange vibrations arise in the water had not been completely cleared up to this day.

There are other stumbling blocks in water-borne seismic prospecting, namely: specific resonance waves, near-bottom and so-called lateral vibrations. This made designers invent special equipment. There are instruments which, like filters, stop interfering waves, allowing only the wanted signals to pass. There are still many invisible bumps in the way of water-born seismic prospecting. But even these obstacles cannot discourage researchers. They know that most of the gas and oil of our planet lies in the invisible depths under the sea.

Soviet geophysicists have already run tens of thousands of kilometres of seismic profiles in the Caspian Sea. They have made it possible to discover new deposits, such as that in the Neftyaniye Kamni area.

The coasts of distant Sakhalin also hold offshore petroleum and gas, 2.5 times as much as the island itself. "Black gold" is produced from the bottom of the Bay of Mexico and in other sea regions of the globe. In about 10 or 15 years as much petroleum will be coming from underwater deposits as from those on dry land.

Some years ago the Soviet Union lagged behind the USA. Soviet water-borne seismic prospecting was born during the most difficult days of the Great Patriotic War. Only in 1952 were piezoelectric crystal transducers first used in the USSR. Now the situation has changed, and it is not by chance that the prominent American scientists G. White and F. Press pointed out: "It is surprising that though work in the field of water-borne geophysics was started in the USSR only a few years ago, the level of their experimental equipment and research results is comparable with the level achieved by the USA, where marine work was started about twenty years ago."

This was said in 1960. Since then our water-borne seismic prospecting has been developing even more successfully.

INVISIBLE SIGNALS

Once in Summer

It happened at Kavgolovo Lake, near Leningrad. One summer day in 1936 some men appeared on the shore and began to unload metal rods from a truck.

Soon the curious noticed that they were not just ordinary rods. They attracted and held all iron objects, for they were magnets. But what were they needed for at the lake, nobody knew.

Nor could anybody understand what happened afterwards. The men who had brought the heavy rods threw off their clothes and took the magnets into the water. There they stuck the rods into the soft floor as if planting out seedlings on a flower bed. Then they fenced in the "planted" area of the lake with buoys.

Some time later these men went out into the lake in an ordinary boat. True, the ever present curious youngsters noticed that the boat carried strange instruments and a rotating drum with a paper tape. What did it all mean?

The thing was that the men who went boat riding on the lake were not simply out for pleasure. They were researchers testing the first Soviet air-borne magnetometer. But then why in the water and not in the air?

As a rule, experiments are made with models. In this case it was necessary to create an ideal model of a terrestrial anomaly, simply to make a sort of artificial magnetic ore deposit. There are no such natural deposits in the vicinity of Leningrad. To bury magnets in the ground would take a long time and a lot of effort. It was much easier to set up the "deposit" at the bottom of a lake, somewhere far from town, far enough from trams, trolleybuses and motors which always interfere with such work.

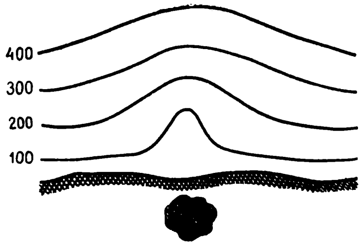
That is what the boys found out afterwards when the mysterious boat returned. One of the young researchers took a stick and right there on the moist earth of the shore drew a little lake, the magnetic rods on its bottom, and above them, a curve. He explained that their instrument would record on tape the attractive force of magnetic ores. Where underground treasures lay, the recorder would draw a "mound" or "pit". These irregularities would help to determine not only the site of the deposit, but its possible size as well.

Soon after the investigations at Kavgolovo Lake a magnetic prospecting plane made its first flight from Novgorod to Valdai. Among the participants of the flight was one of the main authors of the Soviet air-borne magnetometer Alexander Logachev, now Doctor of Physical and Mathematical Sciences and Professor of the Leningrad Mining Institute.

What Is an Air-borne Magnetometer?

Essentially, an ordinary frame with a wire coil wound on it. If the frame is rotated near a magnet, electric current will arise in it. As we know, a magnet surrounds itself with a "cloud" of invisible lines of force. When the wire coils intersect these lines, they absorb their strength, as it were, and a proper e.m.f. (electromotive force) appears in the frame. The stronger the magnetic field, the higher the e.m.f., and conversely, the weaker it is, the smaller will be the e.m.f. Its magnitude can be estimated by means of a galvanometer, an instrument for measuring electric current, plugged into the circuit.

The air-borne magnetometer has many other complex parts. But the basic secret of its operation lies in the remarkable properties of a simple frame with a wire coil wound on it. That is what determines the different intensities of magnetic anomalies.



Magnetic "mounds" above a deposit of magnetic ore.

An aerial prospecting plane usually flies as low as possible above the ground. The magnetic "cloud" is densest down below, dispersing like a fog at a high altitude, and making it more difficult for the air-borne magnetometer to draw a distinct "portrait" of the deposit on the moving tape. Have a look at the drawing. It shows several "portraits" of the same invisible underground deposit, drawn at different altitudes.

Modern air-borne magnetometers are electronic devices, real robots. Take, for instance, the ferroprobe robot. It has two identical cores with two identical jacket-coils set on them and connected so that an alternating current will create two identical, but oppositely directed magnetic fields. These fields destroy each other, as it were, until some external magnetism appears. The latter, like a developer, makes the invisible visible by increasing one of the fields and decreasing the opposite one. As a result, a definite e.m.f. appears in the measuring coil, which can be measured.

Air-borne magnetometers also help in compiling large geologic maps. Rocks usually possess different magnetic properties, which is especially noticeable where fissures occur in the

Earth's crust at the points of contact between formations of different properties and compositions. For example, a gigantic fault extending 2,000 kilometres along the Lena River in Siberia was discovered by air-borne magnetic prospecting. And geologists are sure to find valuable treasures in the vicinity of this fault.

Only a Beginning

We were sitting after work hours in an empty laboratory.

My friend had already read several pages of my manuscript. Now, absently tapping a finger against the plastic housing of some instrument, he was pondering over the critical remarks he was going to make. Then suddenly, instead of making these remarks, he showed me an instrument.

"Here is the basis of an entirely different airborne magnetometer," said he.

"I see. You've got supersensitive mechanisms in there," I guessed.

"No. There's nothing in there."

This caught me by surprise.

"Nothing at all? You mean it's quite empty?!"

My friend smiled and explained that from the point of view of nuclear physics there was quite a lot in there. For instance, a gas consisting of molecules and atoms. And each atomic nucleus has a magnetic field of its own inside. Now if this field comes into another, stronger magnetic field, it will change slightly, and this change has to be measured exactly.

"And what then?" I asked.

"And what then?" echoed my friend and then stopped and thought for a moment. "Well, and then hundreds and thousands of trials have to be made. New variants, new finds... .

"One of these finds, the so-called nuclear resonance magnetometer, I can tell you about in detail. It is a vessel with water."

"With water?" I echoed in astonishment.

"Yes, with water. Inside the vessel is an induction coil through which direct electric current is passed to create a strong magnetic field in the water. The field affects the magnetic properties of the hydrogen atoms in the water, because an electron revolving about an atom resembles a circular electric current. That is why atoms have a sort of personal magnetic field. The electron itself also resembles a tiny electromagnet, because there is something like a circular current inside it too. This circular movement has its own moment of momentum, the spin of a hydrogen nucleus as the physicists call it. The spin orients itself in the direction of intense magnetism. Roughly, like iron filings on a glass held over a magnet. Remember your school experiments?"

I nodded understandingly.

"And now imagine. You turn off the current. The artificial magnetic forces disappear. What happens?"

"Nothing, I suppose," said I without much conviction.

"What do you mean, nothing! What about the magnetic forces of the Earth? Now the hydrogen nuclei will be subject to them and will gradually change their orientation, inducing an e.m.f. in the pickup coil. This signal then has only to be amplified and measured. The best part of it is that this complicated instrument is very simple in design. It can even be used in prospecting for oil formations.

"The air-borne magnetometer will show where and at what depth the basement rocks usually possessing magnetic properties lie. And their bends and fractures often determine the shape of the folds in the overlying strata, the folds where oil may accumulate."

The Same, but the Other Way Around

The professor looked around the hall, then glanced back at his desk and composed himself. The hall was well filled, and the instruments were arranged on the desk in excellent order.

The professor began:

"Today we shall demonstrate experiments with electricity. Here is a vessel," he pointed to a large glass jar. "This vessel, gentlemen, filled with acid in which are immersed metal plates, possesses the remarkable property of creating electricity. It is transmitted from one end of the wire to the other. Attention, please. I am going to switch the apparatus on."

But hardly had Hans Christian Oersted switched on the battery when somebody in the audience cried out: "The needle! The needle is moving!"

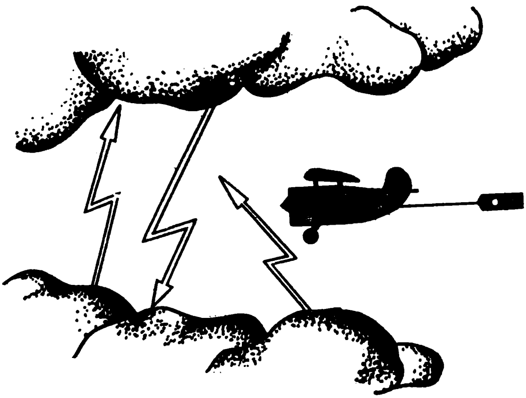
Nonplussed, the professor quickly disconnected the wires and looked over the desk. Everything was in order. Then, keeping an eye on the instrument, he again connected the battery to the circuit, and noted that the magnetic needle of a compass which lay close to the wire began to fluctuate. This was a great discovery. The next year, in 1820, the Danish scientist Oersted published a paper in which he described in detail the action of a current-carrying conductor on a magnet.

He found that electricity could create a magnetic field. Thus, about one and a half centuries ago was born the science that treats of the properties of electromagnetic vibrations. For a long time they were studied mainly by physicists and electrical engineers. But during the last decade geologists have also become interested in these phenomena. They decided to use an electrical apparatus installed in the cabin of a flying airplane to prospect for ores.

Imagine a plane flying through the air. The lights, heaters, and radio transmitter in it are operated by electricity produced by electric machines, say, generators. The air-borne electromagnetic apparatus also has a generator. It produces high-frequency alternating current. But this electricity gives no light or heat and does not energize the radio. It is simply "thrown out" into the air. Geophysicists say it is sent to the outside transmitting aerial.

This aerial greatly resembles the frame with coils of wire we were talking about earlier. Along these wires flows the electric current from the high-frequency generator, and the result is the same, but the other way around: the e.m.f. gives rise to an artificial magnetic "cloud". Like an invisible shower, the lines of force come out of it and rush earthwards. Their "streams" penetrate the soil and rock layers, and in the depths give rise to an e.m.f. in the stony conductors. This e.m.f. is more intense in some rocks, and less in others, because they have different conductivities. All together it makes up a sort of closed cycle.

The electric current induced in the ground by the artificial magnetic field returns magnetic vibrations of its own into the surrounding space. They are picked up by the aerial trap frames. On contact with the wire coils the magnetic "echo" changes into electric current, which runs along a cable to measuring instruments in the airplane cabin. Then the prospectors determine what rocks or deposits these signals are characteristic of. And to decrease the influence of the primary magnetic vibrations on the trap-aerial, the latter is removed a distance of up to 150



Air-borne electrical prospectors enter a storm cloud metres from the plane. That is why an electromagnetic prospecting plane usually has an external gondola trailing after it on a long cable, housing the pickup equipment. The air-borne electromagnetometer creates its own magnetic field, which must not be confused with the natural field of the Earth. Hence, the signal of artificial magnetic vibrations should be stronger than any others.

The natural field can also be of use to geologists. Thunderstorms keep occurring constantly above our planet. Each second there is lightning flashing somewhere and this is a source of electric pulses. They all create a very weak electromagnetic field which encompasses the Earth. Above coal deposits, ore bodies, and other formations of the Earth's interior this field slightly changes its value. It therefore became necessary to determine these changes, and scientists living in the Novosibirsk Academy settlement undertook to design especially sensitive equipment for this purpose. These instruments are also installed in the trailer gondola of the airplane, making the current generators gratis and lowering the cost of prospecting by a factor of three to five.

Dreams and Reality

In the early fifties I worked with an expedition operating a УР-4 radiometer, an instrument for determining the radioactivity of rocks. I would carry it all day over the wilderness. In the evening after supper I would stretch my weary feet towards the warm glow of the fire and dream aloud.

"See the green lights of an airplane up there, on the right of the moon," I said once to my chief. "Wouldn't it be nice to be able to sit in its cabin, watching the scales of instruments and compiling our chart. We could then cover not 25 kilometres like today, but all of 1,000. No damp boots, no heavy rucksacks. Work would be a pleasure. And we could rest differently. You and your friends could play chess or read a fresh newspaper. And I would be off to the movies or to the park above the river! What bliss!"

My chief only grinned: "Oh well! In about ten years' time even that may come true."

But he was wrong. That same summer the first radioactive prospecting airplanes rose into the sky. Today this method of prospecting has become quite routine in geological exploration.

But how can geologists in the sky see radioactive ores under the ground? How do they distinguish and find the deposits they are looking for? The point is that many rocks send signals of their presence into the surrounding space. Sometimes these signals are very weak gamma-rays, so weak that they are quite imperceptible to living organisms. That is why nobody ever feels these radiations. Only special, very sensitive instruments can "see" them. Such instruments are radiometric counters. If such a counter is placed close to the granite steps of a house or to a stone sidewalk, the radiometer will record a very small but quite perceptible radioactivity. Do you know that the familiar rock granite is one of the highly radioactive rocks? True, it contains only traces of the radioactive elements uranium, thorium, and radium scattered among other minerals. Therefore, for commercial purposes we have to find the rocks containing the highest accumulations of radioactive elements, and such rocks would evidently have the highest gamma radiation. Everything seems quite simple, doesn't it? Radioactive deposits betray themselves, as it were.

At such sites gamma-rays spurt from the earth like a magic fountain, rising tens and hundreds of metres above the ground. All you have to do is take a radiometer, get into an airplane and fly off into the air. In this way not 25 but 1,000 kilometres of the Earth's surface can be surveyed in a single day.

But up there not only the radioactivity of local rocks will be registered. A sensitive radiometer will simultaneously notice the presence of cosmic particles, which have arrived from distant space. It will "see" gases, the products of radioactive irradiation, such as the emanation thoron and radon brought by the wind from other localities. The radiometer will add many other things to its record.

Is such a tangle of different recordings easy to decipher to single out that of the local radioactivity below the wings of the flying airplane? No, it is not. It requires involved mathematical calculations. To put it scientifically, authentic interpretation of various phenomena is necessary. That is why scientists were not able at first to use air-borne radiometers. But now a great deal has already been studied and solved. Today interfering signals can be taken into account automatically.

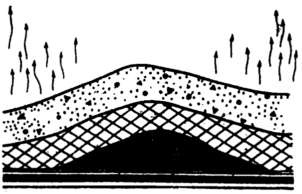
How is a geological survey made by the aerogamma method?

First airplanes take off for a preliminary study of the terrain. They determine the ordinary radioactivity, i.e. the background of the rocks in the region under survey. This background is used afterwards as one of the corrections in the calculations. Then the survey begins. An invisible network of routes is traversed in the air at an altitude of 50 to 100 metres with the radiometers switched on. The geophysicist or an automatic computer immediately processes readings, makes the necessary corrections to account for the altitude of flight and the terrain relief. Then the routes are drawn on a geologic map, indicating the radioactivities found. And now the areas of increased gamma-radiation become visible. It can easily be seen where final exploration should be done. That is how deposits of radioactive elements are sought. Oil and gas deposits can be prospected in the same way.

Petroleum Will Also Become Visible from an Airplane

How? I asked a geophysicist, and he answered: "Where there is a lot of petroleum, gamma-radiation decreases, sometimes to 3 or 4 times below the natural level of the Earth's radioactive field."

Then I asked a geochemist, and he replied: "You know, of course, that gasoline and kerosene have odours? This is the smell of evaporating hydrocarbons. The rock strata 'inhale' these fuel-mineral vapours, preventing sorption, i.e.



Radioactive signals from the Earth's interior report the possible presence of petroleum.

takeup of radioactive elements. That is why the radioactivity above an oil deposit decreases." Such was the second answer.

I heard a third from a lithologist, a specialist concerned mainly with sedimentary rocks: "My colleagues are right in many points. But it seems to me that they forget that the instruments used in radioactive prospecting record only the radiation of the surface layers. I believe this shows that the reason for the decrease in gamma-radiation is under foot. Take, for instance, clay. It is the best sorber of uranium. Sand or sandstone, and limestone have a lower sorption capacity, and that is why their radioactivity is lower.

"You probably know that petroleum occurs most often under arches of the Earth's strata. Many of these arches, called oil structures, are still changing their shape, moving and bulging. Of course, rain and wind wash away and blow off more and more clay particles from their 'crowns'. And less clay means weaker gamma-radiation, doesn't it?"

Indeed, many of the petroleum folds of Siberia, Bashkiria, and the Krasnodar Territory are still in active motion. In all these cases the Earth's radioactive field has been found to be depressed. A glance at the simplified drawings of a deposit of this kind shown above will make many things clear.

An airplane takes off from the airfield. Below lies the impassable swampy Siberian taiga. The inexperienced passenger looks down and thinks: "It would be difficult to see anything down there, not only deep-seated petroleum." But the experienced aerial prospector does not even have to look down. Sensitive radiometers automatically show the probability of occurrence of oil deposits. This method of prospecting for petroleum is a thing of the near future.

"Molybdenum Ore to Seek ..."

The title is a line from a favourite song of Soviet geologists. They put a lot of effort into prospecting for this rare metal. The automotive, aircraft, and machine-tool industries all require molybdenum. It is needed very much in chemistry too, because it is resistant to reagents, especially where organic synthesis is concerned. Electrodes containing it give the strongest welds. "Grains" of molybdenum added to nonferrous metals make them quite resistant to corrosion of all kinds. Then, radio and electrical engineering also need molybdenum and its companion tungsten. Gas turbine parts, jet engines for high-speed aircraft, thermonuclear reactors and cosmic units—such is the range of application of these wonderful elements today.

They are sought everywhere. In the Transbaikal, for instance, molybdenum and tungsten are often concealed in rocks resembling granite.

These granitoids possess increased radioactivity and are very feebly magnetic. Hence, having maps with regions of minimum magnetism and maximum radioactivity marked on them, prospectors can predict where molybdenum is likely to be found.

Air-borne radiometers can be used in the search for precious diamonds too. They usually occur in kimberlite pipes, where at some time in the past the red-hot funnels of erupting volcanoes rumbled. These pipes are often also surrounded by granite rocks. Granite is highly radioactive, but the radioactivity of kimberlite is very low. Hence, weak gamma-radiation may be a sign of diamond-bearing ground.

Knowing the radioactivity of various rocks, geologic maps are compiled for each locality. This makes it possible to detect faults in the Earth's crust which are hidden under loose drift material. Then sites presumably rich in rare and nonferrous metals are marked out. These places always contain small amounts of uranium, thorium, or radium, and therefore their gamma-radiation is higher.

And These May Betray Themselves

Have you heard of lithium?

It is also sought intensively, though it is present everywhere. It is contained in living organisms, in plants, and in common rocks. Granitic pegmatites are often one quater minerals containing this element. Nevertheless it is classed as a rare metal. We may add that it is softer than wax, lighter than a splinter, and burns like a match. We are accustomed to thinking that rare metals are noted primarily for strength and heat resistance. But lithium can easily be cut with a knife. It floats in kerosene, does not sink and bursts into flame in water. It feels hot at room temperature, and its "face gets tanned", becoming coated with a dark film of oxide. No high-temperature electric furnace is needed to melt this metal; it melts in the heat of an ordinary hot-plate, because its melting point is only 180°C. Molybdenum and tungsten are still hard as stone at +1330°C, but lithium evaporates and disappears at this temperature. And now, just think, this soft, unstable element was given the impressive name of "stone", for such is the meaning of the Greek word lithos from which is derived the name "lithium" given it by the Swedish chemist A. Arfvedson who discovered the element in 1817.

Now who might need such a weak metal? Neither metallurgists, nor machine-tool builders, nor automobile manufacturers, it would seem. Maybe that is why lithium remained a "waif" up to the forties of our century. Then it was suddenly found that all mankind needed it. For lithium has a direct bearing on the production of thermonuclear energy, and this is the energy of the future.

Lithium is a fuel for launching space rockets and artificial earth satellites. In the form of its hydride lithium helps to fill radio sonds with hydrogen. In another form it cleans air of harmful carbon dioxide, CO_2. Added to lubricating oils it makes them resistant to icy cold and to tropical heat, as well as high humidity. Isn't it the car driver's dream to have a single universal lubricant instead of a whole assortment of grades? In metallurgy this element is used as a degassing agent for absorbing harmful gases which deteriorate the structure of the metal. Lithium enamel is an ideal coating, which can be applied to a surface as easily as paint. Television tubes, reflectors, and high-grade optical glasses also require lithium. It is a growth stimulant in agriculture; for instance, lithium carbonate is an important aid in tobacco growing. Lithium can be used for air conditioning in the home, and for absorbing moisture in refrigerators. Who has not heard the distracting click-click of chalk on a blackboard? An insignificant addition of the element to the mass used for coating the blackboard surface, and this sound disappears, becoming toneless. Lithium is also needed in the production of vitamin A and for improving certain cosmetic creams.

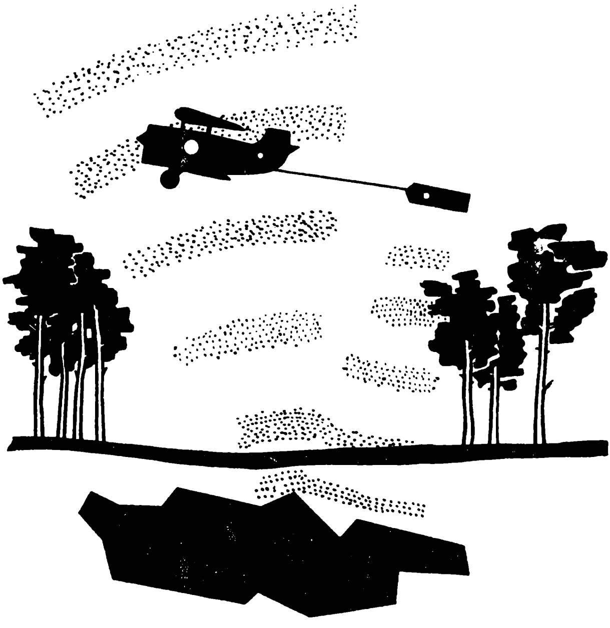
So what's the matter? It is needed everywhere and occurs everywhere. Why not just go and mine it?

Unfortunately, because of its high chemical activity, lithium occurs only in combination and its compounds are widely distributed but in small concentrations, uneconomical for industrial mining.

Geologists seek primarily deposits comparatively rich in lithium, and use the most up-to-date methods in exploring them.

There is no need to explore every square inch of ground and to state regretfully: "There is lithium here, but too little of it." A gondola with a radioactive generator is fastened to an airplane so that it trails after it at some distance, and gamma-rays rush down from it to the earth. Here they encounter rocks, and the latter send back "yes" or "no" signals. A sensitive pickup should register the induced radiation, as specialists call it, of the isotope of the element sought.

Not only lithium but aluminium, copper, silver, boron and other deposits can be found this



Induced radioactivity signals the presence in the interior of aluminium, copper, silver, etc.

way. The induced radioactivity method eliminates expensive chemical analysis of rocks, and therefore has a bright future.

Incidentally, there are those who believe that this method can be used for petroleum prospecting too. Unlike the surrounding rocks, petroleum and gas are poor emitters of induced radioactivity. Hence, a sharp weakening of the response signal should put the prospector on the alert.

Radioactive methods can be employed not only for prospecting for unknowns, but also for reviving old deposits, for getting more precise information on what is known only approximately.

Prospecting down a Hole

Explosions echoed through the Carpathian foothills. And keeping time with them a flame bobbed up and down in the yard of the oilfield head office. Paper was burning. Letters and figures, drafts and tables were reduced to ashes. Before retreating the hitlerites were burning all information on the oil deposits of the West Ukraine. Whoever returned here would have to start all over again. That is what the fascists thought.

But it was a miscalculation. The documentation was restored quickly and cheaply with the aid of nuclear geophysics, mainly by gamma-logging.

Geologists drilled only a few base wells and took rock samples from them at different depths. Then they determined the intensity of gamma-radiation of each sample. After this no time or money had to be spent on removing rocks from other holes. Natural radioactivity recorders lowered into the holes reported what there was down there, and where, and even gave data for calculating the thicknesses of the layers.

The same method is used at potassium salt deposits to determine the exact percentage content in the bed.

Double gamma-logging is also employed. Together with the radioactivity recorder a source of hard gamma-rays, such as cobalt-60, is lowered into the hole. Its radiation, reflected from the rocks, is recorded by a self-recorder.

By this method the location and thickness of coal seams can quickly be determined.

Double gamma-logging with soft cesium-137 or selenium-37 rays helps to calculate the content of heavy metals over the hole section.

Electric logging is used in holes, apart from radioactive logging, to determine the electrical conductivity of minerals. Equipment has been devised for studying the magnetic properties of rocks in a hole.

Some of these instruments were developed by V. Meyer, a young researcher of Leningrad University. Then he took an interest in radioactive phenomena. He performed experiments day after day and compared their results. And after some time he discovered a previously unknown regularity.

Careful analysis of all available data suggested that this was atomic fluorescence, a specific X-ray radiation of an element, caused by bombarding it with gamma-rays. Since each element has its own individual fluorescence, this plainly suggested that in deposits containing, say, lead, tungsten, molybdenum, mercury, and barium, the quantity of each of these elements could be calculated separately by just lowering the instrument into the hole.

When the researcher spoke about these ideas to authoritative experts they said that down-the-hole conditions were too complicated for X-ray radiation and that such results could be due to any other cause.

But the geophysicist from the university did not give in. It was decided to make a trial in a hole known to contain only worthless rock and no economic minerals.

Instruments tuned to record fluorescence were lowered into the dark hole and suddenly a jump appeared on the diagram, signalling the presence of lead. It seemed that the scientist was mistaken.

Yes, he had been mistaken, but not in his ideas. On re-examining the equipment a defect was found, which had been the cause of the false lead signal. Subsequent trials confirmed the discovery. The new method of down-the-hole prospecting turned out to be much better, cheaper, and simpler than any other method.

As you see, even atomic fluorescence—a complex physical phenomenon—is at the geologists' service.

Only a large number of divisions of higher mathematics remained aloof from mineral prospecting. Indeed, signs and formulas on paper, and an actual deposit in the interior. What is the sense of bringing together abstractions and reality? But there are different ways of bringing them together.

Not a Needle but Gold

Young Georges Louis Buffon spent a lot of time on the seemingly senseless occupation of throwing needles on the floor. Who would think there was anything remarkable in finding out how many times the needle intersected the boundary between two floor boards. But as a result, Buffon published a book in 1777 entitled *A Test in Moral Arithmetic.* This curious title stood at the head of the theory of probability as applied to geometry. In this way the scientist confirmed the constancy of the famous number π.

More than a hundred years later the test was repeated by Fox, who threw a needle on the floor 1,120 times. Then he calculated the number π according to an appropriate formula and found it to equal 3.14. In 1901 Lazzarini patiently threw a needle on his floor boards 3,408 times. But of course π remained the same.

In all these calculations nobody ever forgot to state the length of the needle, the width of a floor board, the total number of throws, and the number of intersections with the boundary between two boards.

Thus, we see there is a close connection between the abstract and the concrete. One takes a series of values and on their basis one calculates a definite regularity.

Then why not do the same in geology? For instance, one could choose a series of signs, observe them, and then calculate the most probable relation between these signs and the minerals sought.

Geology is only starting to make use of quantitative measures. At least there are many that think so. But are they aware that Charles Lyell (1797-1875), one of the founders of this science, studied ancient seashells, compared them with modern ones and then calculated the probability of modern shells occurring in more ancient deposits.

As far back as 1899 N. Psarev, a practically unknown Siberian gold prospector, wrote: "Suppose that consecutive washing of each n poods of gold-bearing sand in a prospecting shaft showed the gold contents: a, a^{I}, a^{II}, a^{III}, ... a^{n}." This sentence in the prospector's diary is followed not by general reasoning, but mainly by signs and figures. The ultimate result was the following conclusion: "Knowing the average gold content for the area explored, the thickness of the bed and the overburden, and having an exact plan of the prospecting site, one can calculate the workability, and the kind and cost of operations. Now has not this something in common with Georges Louis Buffon's passion? Only passions can be different. And the theory of probability can be applied not only to geometry, but to geology too. Accordingly, the initial data will be the needle, the floor board, and the number of throws in the former case, and gold, a bed, and samples, in the latter.

Mathematical Statistics and What It Can Yield

It was hardly what Academician Ivan Mikhailovich Gubkin was after. But once when he was studying the oil-bearing areas of Bashkiria he noticed a bleached rock, and... was thus the first to apply mathematical statistics to oil prospecting.

Thus, there is a sign: a bleached rock. It may have been bleached, in particular, by hydrocarbons, chemical compounds contained in petroleum and gases. The rocks under which a mineral deposit occurs are also chemical compounds. Therefore the hydrocarbons rising from the interior to the surface react on their way with the rock strata, removing oxygen from them wherever possible. In the language of chemists this is called reduction and as a result of it brown clays and sandstones become greenish-grey.

But rocks may also be bleached by other chance factors. Therefore the geologist's main task is to foresee the relative frequency of recurrence of a chance event. This is the basic measure of mathematical statistics in geology, and is also the language of mathematics.

Collections of minerals or of the remains of extinct organisms have been studied, the structure and composition of rocks investigated, and entries made in field diaries for years and years. Geologists have always essentially been close to statistics. Only they were mostly subjective, and even one-sided in their conclusions.

Sampling of a diamond deposit showed no relationship between the crystal size and closeness of the crystals to the edges of the kimberlite pipes. This led the diamond prospectors to the conclusion that the crystals had formed at a great depth and were subsequently raised to the surface in a disorderly mixture with the surrounding rock. On the correctness of this conclusion depends where and how to mine the diamonds. But may be it is wrong? Mathematical statistics can supply the answer.

Diamonds again. Suppose they occur as little pyramids. You might consider this a detail of secondary importance. But then the faces of the diamonds would be even less important! One of them is a bit longer, another a bit shorter. Is this worth paying attention to? But geologists have taken an interest even in such "trifles" though they know they cannot as yet tell why they are different, because diamonds are thought to have been born in the fiery "hell" of magmatic volcanic pipes.

Alum is quite another thing. Its properties have nothing in common with those of diamonds. But its crystals have the same shape. Alum is a sort of model of a diamond, which is easy to grow in saturated solutions. Scientists took advantage of this to find out what kind of solutions pyramids are most likely to form in. Then they counted up the results of many tests, summed up their results and concluded that diamond pyramids should form mainly in magma highly saturated in carbon.

Thus, comparison of seemingly casual features and modelling can yield important conclusions, if aided by mathematical statistics.

Cybernetics! Can It Be?

Spring flood time. The last ice floes float by, carrying boulders, sand, and all kinds of debris.

Suppose somebody asked you to describe this picture in numbers: "First there was 5, then

2, then 32, then again 5." The numbers do not seem to mean anything, do they? However...

A spring programme over TV. Again the spring flood with ice floes floating past, carrying boulders, sand, and other kinds of debris. Points follow each other in quick succession over the screen, forming the image. And each point has its own brightness, depending on the size of the electric signal it represents. It may be one unit, or twice as strong, two units. In general, the signal may be any number of units. As to the image, it is a series of different numbers. Hence, of the entire picture observed one may say: "First there was 5, then 2, then 32, and again 5." The numbers here are a kind of measure of information. All the numbers taken together are the total information.

It is to obtain the latter that geologists carry out their investigations. They study the interior to gather data on the source of information, for instance, on an oil deposit. Such data may be called signals. One of the signals of petroleum is bleached clay or sandstones. The layer of sediments covering the petroleum is a kind of traffic channel. Probably the best traffic channels would be prospecting holes if they could be drilled right down to the deposit, to the source of information.

Thus, a deposit, the overlying rock layers, and the prospectors on the Earth's surface are a kind of communication system. Hence, communication theories, mainly the theory of systems control and the theory of information, may become geologists' helpers. And this is the field of cybernetics.

Several years ago Academician Aksel Ivanovich Berg wrote: "Science progresses from general qualitative estimates to the establishment of exact mathematical quantitative regularities." That is the way Earth science is developing now. Numerical regularities will be discovered between finds of fossil organisms in certain deposits. An interrelation will be established between the smoke of volcanoes and the power of their eruptions. The taste of water flowing through different rocks will be designated by numbers. In the future even important periods in the geological history of our planet will be explained in quantitative terms.

For instance, geologists have long known that there are two main structural varieties in the Earth's solid crust: mobile zones called geosynclines which are often regions of mountain formation and tranquil regions called platforms because they are frequently level. Such areas of the Earth's crust differ sharply in many features which can already be calculated quantitatively. But there are also transitional zones. Probably they could also be characterized by definite numbers, and this would facilitate the development of a more detailed history of geological processes.

Our planet, like many other things, is a complex set of cybernetic systems. To find out what governs them and how they are governed is the task of scientists.

Diamonds Found in Scientific Papers

You need not question this title. It is the truth. The diamond deposits of South Africa, Brazil, and India have been known for ages. There are multitudes of articles and books describing the rocks characteristic of these regions and the unwanted minerals occurring in them together with the greatly wanted diamonds.

At one time practically no diamonds were ever found in the Soviet Union, except for one or two finds in the Urals. But geologists had at their disposal scientific literature containing detailed information on the diamond wealth of distant countries. It treated of the bluish clay encountered together with the precious stones. In the deep interior this clay is represented by a hard greenish rock called kimberlite.

The little printed letters added up into information on other rocks accompanying diamonds, pink-red garnet crystals, for instance. V. Sobolev studied this information very carefully, compared it with investigations of the minerals of distant Yakutia, and suggested that there might be diamonds there.

Time passed, and persistent searches resulted in the discovery of volcanic types similar to those of South Africa. Thus were found some of the world's richest deposits of this much needed mineral.

And so we see that the first thing required to predict the discovery of diamond deposits was scientific information. This comprises figures, tables, reports of geological expeditions, and articles published in periodicals—an immense sea of information, from which the necessary data have to be "fished out".

And, of course, electronic computers may become excellent helpers in this task.

"The best way will be to cover a small area with a network of foot routes and take metallometric samples," said the geochemist.

"No! At this point it will probably be more reasonable to carry out a radiometric survey, and thus cover more ground," replied the geophysicist.

"You seem to be forgetting that the terrain is swampy, and that will make foot routes difficult to accomplish. I think both versions you have suggested are uneconomical," objected the geologist.

Then the chief of the prospecting expedition summed up:

"Unquestionably, what we should aim at is a combination of economics and maximum efficiency. Each of us has made points pro and con. Evidently these points are influenced by the speciality of the author and his habits in using known methods. Hence, we shall leave the final decision of our debates to an objective valuer, namely, the БЭСМ-2 electronic computer. Any objections?

"So now, our common task is to supply the EC operators with all the information on which the prospecting efficiency depends. This includes information on the natural conditions of the area, indicating how much of it is marshy and how much solid ground, on the scale for geological surveys, and, of course, on the prospecting methods to be used."

For a long time that day the members of the future expedition discussed the plan of the assignments for the БЭСМ-2 electronic computer.

Some time later the geologists got together again, this time to study the tables prepared by the EC. These tables did not contain the words "marshiness" or "radiometric survey", but conventional signs and numbers—a, b, c, A, B, C, 3, 7, 8, etc., and there was nothing to argue about. The EC had decided all the doubtful questions by itself.

The time spent on calculations and preparing the information for programming was more than repaid. It took only a few days instead of many months to find the very best method of exploring the area.

In the case described the task was not a very complex one, and the preliminary data were readily coded as numbers and signs. But this is not always so. An electronic computer knows only one general language, that of mathematics, a language based on strict logic.

And this is where geologists came up against difficulties. Geology is the study of the Earth. Palaeontologists, for instance, have to do with ancient fossils, where biological concepts are indispensable. Mineralogists investigate minerals and use mainly chemical terminology. In other branches it is especially important to know the laws of physics. Hence, apart from the concept common to all branches of geology, there are many specific ones used only in a definite field. Different geological terms could fill whole volumes of glossaries showing that even specialists in the same field of knowledge think about the same thing in different languages.

A study of such terms from the point of view of their logic was carried out at the Siberian Branch of the USSR Academy of Sciences. It was found that only a small percentage of the terms examined could stand all the tests quite rigorously.

Hence, one of the main tasks at present is to create a uniform scientific language for geologists of all specialities. Solution of this problem would pave the way for the use of electronic computers in geology.

Just now EC are only breaking their first footpaths in geological prospecting. But even these footpaths strike the eye immediately. Here are some examples.

During exploration work the geologist usually records all his data in notebooks—field diaries, record books, and the like. Afterwards the researcher has to go through tens and hundreds of such records to generalize and analyse the material he has collected.

Geologists with small cards in their hands, appeared at the Kokpatas gold deposit in the Kyzyl-Kum desert. On these cards they coded the features of deposits not in words but in numbers and by means of holes corresponding to these numbers and located at strictly definite points. These were punch cards to be filled in right at the deposit. The next step was to feed them to the EC for calculation.

An electronic computer can quickly analyse dozens of different geological factors and prospecting signs, and conclude whether the ore field is highly prospective, prospective, or neutral and non-prospective. The abilities of the electronic brain were checked for a well explored ore deposit of Middle Asia, and its conclusions confirmed available data on the prospects of this underground treasure. But the EC went on to outline three new areas for prospecting. The very first tests on two of them showed the prediction to be true.

Can the EC be used for petroleum prospecting? Are there any mathematical methods by which the presence of petroleum reserves can be predicted? Workers of the Institute of Geology and Geophysics of the Siberian Branch of the USSR Academy of Sciences and the Siberian Research Institute of Geology, Geophysics and Mineral Raw Materials attempted to answer these questions. To do so they made an album of algorithms—mathematical operations to be carried out in a strictly definite order. They also compiled programmes for treating geological data. Now the EC can even answer such a tricky question as "where do oil-bearing formations occur and where water-bearing layers?"

When investigating holes geologists compile what is known as logs. To prepare each of them for the EC, the computer operator has to measure about 15,000 amplitudes with a ruler, record the data in a table on a keyboard punching machine, code the diagram values and check the numbers recorded on the punched card. As you see, preparation of materials for electronic computers is not an easy job.

And so the Novosibirsk geologists organized a comprehensive mathematical group. All through the winter of 1966 the researchers prepared intricate schemes and devices. Test after test was performed and oil prospecting expeditions were made. So was born the КОД-1 semi-automatic machine. It does all the preparatory work 220 to 400 times as fast as a man. Its only shortcoming is that it needs one operator. But even he will soon be replaced by a special device. And then the automatic machines will themselves produce all the materials for the electronic computer.

So is the real abstracted only to return embodied in the concrete.

And now let us return to one of the most familiar things in the life of any person, to ordinary water. If you only knew how much trouble it not infrequently causes those who seek it, this familiar but invisible thing concealed in the Earth.

CROSSWORD PUZZLES OF THE FAMILIAR

"Signs" and Signs

"Keep your chins up, brothers!" The speaker screwed his eyes up smugly and glanced over the crowd of settlers. Then he reached deep down into his homespun trousers and pulled out a book.

"Look here!" he cried, waving the book above his head. "Here's a wise book. Fetched it from town, I did. It's called *How to Find Water.* Listen, while I read."

The farmer turned over several pages, ran a dirty finger down the page and began to read haltingly.

"Take a, ahem, supple green twig of hazel or elder. It should be forked; if it isn't, bend it as shown in the drawing.

"Hold back, men, hold back there! Ye can look at the picture later!" He put off the curious, then continued:

"Ahem. This twig is called a divining rod. Hold the rod in both hands turned outwards straight before you and walk with it over the area where it is desired to find water. When the rod begins to dip, you can expect to find water at that point. By the extent to which the divining rod dips, you can judge how close the water is to the surface...

"See?"

The answer was a hub-bub:

"It's clear. Come on, let's look for water before it gets dark."

"Wait, there's a hitch," the settler stopped them. "Listen to what it says afterwards:...

'Cases are known where 97 wells have been found in 100 attempts by this method. Of course, the diviner must be honest...'

His chin began to tremble:

"If that's the way it is, we'll need someone who's free of sin."

The settlers fell silent and scratched their heads:

"How about Benny?" someone suggested timidly. "The lad's still innocent."

"That's right! Benny! Benny!" came shouts from all sides. A little boy in a long smock reaching down to his knees, his black eyes wide with fright, was shoved out of the crowd into the circle. Someone handed him a supple hazel twig. Full of wonder Benny took it. Then with an air of great importance he began to walk through the hushed crowd.

Soon he was out in the open, the men giving way with their eyes fixed on the end of the twig. It shook and trembled in the boy's weak hands, and it seemed to the farmers that any moment it would show where the precious water lay!

For a long time they walked about like that. And it began to seem as if it were... But all in vain...

That is how it used to be. A few decades ago such advice for finding water was given in books, whose authors referred to folk "lore". Of course, there are signs and folk lore that have a scientific explanation.

Here, for instance, is a way of looking for water, used in the south of Russia: during hot weather the turf would be removed from an area of 3/4 square metres, and a sheepskin would be spread hair upwards on the bare, absolutely dry ground. On the sheepskin was placed a fresh raw egg, which was covered with a glazed pot. Next morning at sunrise the pot was removed. If the hair and egg were covered with dew, there was water there, but it was deep down. Of course, the reader will appreciate that many of the objects named were unnecessary, being only a tribute to ancient customs. It would have been sufficient to place an overturned glass or a pan with dry cotton wool on the cleared area and have a look after some time. If the cotton were moist there would be a point in looking for water. Why?

Let us see. Who has not noticed during hot dry weather a light cloud of mist rising over the ground in the evening or in the morning, especially in low places. Under this cloud is usually its source, which may be an accumulation of subsoil moisture. Evaporating from the warm layers of the ground, it comes in contact with the cold air and recondenses into tiny drops of liquid, forming a fog. Day comes, the sun becomes warmer, the grass waves to and fro in the wind, and the fog disperses.

A similar thing happens under any overturned vessel, with the difference that in this case the water droplets fall into a trap. The glass walls keep them from evaporating and disappearing.

Another way of finding drinking water is through plants. For instance, black poplar, bullrushes, horse-tail, and large-leafed sorrel are indications of a spring nearby. You can easily trace the path of the latter by looking attentively. The plants are nourished by the moisture and they always try to follow it.

Summer time in the virgin plains of northern Kazakhstan. White tassels of goats'-beard wave in the wind, spreading a honey-like smell, yellow umbels of spurge peek out from the lush dark verdure of grass and sedge. Here and there gleam the purple-red heads of pimpernel flowers. A man comes out on the plain and his heart fills with joy. He not only sees the flowers but knows that there are ground waters somewhere close to the surface.

Still another sign of water is what are called "bidayeki". That is the local name for depressions resembling immense saucers. Not infrequently up to 50 of these can be found on a single square kilometre of area in the plains. And wherever there are lentils of leakage water in these "bidayeki" wheat-grass thrives. The Kazakh for this weed is "bidayik". It will not disappear even in a cultivated field and is a good sign of depressions on arable land.

How the Lake Ran Away

This happened... but let us start from the beginning. The orchestra struck up a flourish and a lake was born in the beautiful setting of the French Alps. The stony bottom of a canyon, slightly covered with drift; sheer rocky banks; the swift Drome River blocked up with a dam built in its path. "That does it," thought the builders.

But a few months passed and the lake dwindled to nothing. It did not flow away or overrun its dam, but just dwindled away. Why? That nobody could say. A special commission looked over each metre of shore, but found nothing. Then a great deal of cement was brought and even the minutest cracks were plugged up just in case. After this the lake's birthday was celebrated a second time. Now the builders were quite sure of themselves; there was nowhere for it to go. But the treacherous reservoir again began to dwindle. And at what a rate! A whole trainload of water disappeared each hour, almost 800 litres per second. What was the matter? What invisible outlet did the lake have?

Engineers could only spread their hands helplessly. And the superstitious, watching the shores go dry, whispered: 'Tis God's will; verily, 'tis God's will."

After some time the three hydrogeologists arrived at the Drome. Without much ado they unpacked coils of ordinary wire, metal rods, and a few instruments, and made their way up the mountains.

Here and there they drove iron prongs into the ground and put up wires. They wrote down the readings of their meters and drew strange curves on sheets of paper, resembling the wavy hair of local dandies.

Some laughed at them, others told them to quit their nonsense. But the scientists continued their work and when they were through with it they said:

"The water runs into that big cliff."

"Impossible!" was the reply. "It is solid rock. Anybody can see that!"

"There are through cavities in it," repeated the scientists stubbornly. "Open the cliff and you will see."

Since the scientists had been called out, they had to be believed. So the sly lake was emptied once more, this time on purpose.

A tunnel run through the monolith soon struck a cave, then a second. Now people regarded the strange metal "objects" with respect and listened to the scientists.

It became apparent that the water had seeped through the loose deposits on the bottom and there, unseen by anybody, had joined the underground flows to disappear quickly in the subterranean fractures of the cliff.

That is how, almost four decades ago, at the dawn of new methods of hydrogeological prospecting, the question of "how the lake ran away" was solved.

What was it that helped the hydrogeologists to look into the dark interior and see the right thing?

It Was Electrical Prospecting That Helped

Many objects allow electric current to pass through them. Only some of them transmit it freely, others very unwillingly: they offer resistance to the passage of current. Rocks also possess these properties. And since they differ from each other in composition and structure, they have different electrical resistance.

Now imagine a cube of solid rock, each side of which is 1 metre long. Its electrical resistivity is very large. Such a cube was taken as a reference value. Then it was broken up and soaked thoroughly in water, after which the resistivity of the resulting mass was found to have decreased by hundreds of times. Now how did this happen?

The point is that rocks are mostly electrolytic conductors, whose conductivity depends primarily on aqueous solutions. The more moisture there is in the Earth, the more dissolved salts it contains, the easier will current pass through it.

The resistivity of the dry sand-and-gravel bank of a river would be about 300 ohm·metres. Just a little below the surface of the ground the bank is moist, and here current passes much more easily, the resistivity being not more than 30 to 150 ohm·metres.

It would be a good thing, wouldn't it, if rocks were the same everywhere: down in the interior and up on the surface. Then we could easily tell where it is dry and where it is wet. But this is very rarely the case. Usually when you dig into the ground with a shovel you find a bit of sand here, some clay there, while in a third place there is an outcrop of solid limestone. A whole assortment of rocks! Therefore their resistivity has to be found by calculation from different measurements and even so, it is not their true, but apparent resistivity. This is the basis of the theory of hydrogeological electrical prospecting.

And now for practice. Today you may see hydrogeologists in the plains of Kazakhstan and western Siberia, near the Caspian Sea and along the Volga, in the South Urals, and elsewhere. They need no expensive and cumbersome equipment. They drive metal rods into the ground at definite distances from one another and connect them to batteries to make a direct electric current pass through the ground.

Then two more electrodes are driven into the soil between these rods. They are connected to a measuring instrument called a potentiometer, which shows the difference of electrical potentials and the intensity of the current passing through the ground. From these values the apparent resistivity of the rocks can be calculated and from the results obtained the water content in the area can be judged.

Many readings have to be taken. And so hydrogeologists walk in straight lines up hill and down dale often passing deliberately right across obstacles. Here and there they drive in their finder prongs, taking care that the distance between them is always the same. Then they draw on graphs and maps the profile of water-bearing layers in the ground under the path they have trodden.

This method of prospecting to a definite depth is called electric profiling. It is a good method for investigating not very deep-seated strata and water lenses, ancient river channels buried beneath drift material, karst water-bearing zones and areas of rock fractures if they contain moisture.

But electrical prospecting helps not only to get a glimpse under the ground and to find water. It can even determine the taste of the water, count up the number of "liquid layers" and even indicate the depth at which each of them occurs. In the Earth's crust water-bearing rocks most frequently alternate with rocks that are impervious to water. Sometimes one of the "floors" is inhabited by fresh water, and another, by salt water. This is often the case in the steppe districts of Kazakhstan. Now, how are you to know which is which without digging? At times you do not know even if you do dig. For instance, at the "Shartondin" sovkhoz in Tselinograd Region, a well was drilled for drinking water, but it gave unpotable water. A second one was drilled, but the water was again salty. The people began to worry: "Maybe our sovkhoz is located in a bad place? What are we to do?"

Hydrogeologists came to their aid. They set up the tripods of their instruments, and some time later they said: "Drill here." The third well yielded water. It was at an entirely different depth than had been expected. In this case the hydrogeologists used a method called vertical electrical probing, VEP for short.

To probe means to investigate inwards. Let us see what this means. The longer the diameter of a sphere, the greater will be its volume, and vice versa. So it is with VEP. Changing the "diameter", i.e. the spacing of the feed electrodes will change the volume of ground through which current is passing, and it will include deeper-seated rock strata, or, if necessary, only the surface layer.

In such work the unit remains stationary and only the ends of the feed conductors are moved closer together and farther apart like a pair of compass legs. It has been calculated that their spread should be approximately five times greater than the depth of prospecting.

The measured data are plotted as graphs and compared with theoretical curves given in albums. Wherever the water is salty the apparent resistivity will be low. Where the water is good and fresh it will be high, but much lower than in areas where there is no moisture. It should be added that electrical prospecting is many times cheaper than exploration drilling. The equipment of an electrical prospecting expedition is portable and light, unlike drilling rigs which weigh many tons. And now more and more frequently one encounters in the arid steppe regions of our country prospectors with a double profession—geophysicist-hydrogeologists.

Some may think it at best a useless occupation, to win water from the ground and then pump it back again. Indeed, hydrogeologists look for water at one place, and drill wells to get it out. Then they pump the water to other wells and force it down them back into the depths again. What for?

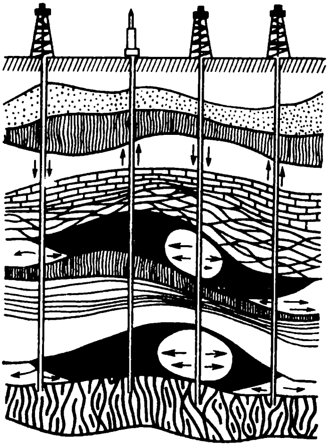
To explain let us consider a case which may seem irrelevant at first glance. Prospectors were searching for gas in Tadjikistan near the spurs of the Gissar Mountains. They drilled several deep holes, and hot fountains of medicinal water gushed out of them. And so instead of a gas workers' settlement there arose the "Shaambary" health resort and an excellent mineral water of the same name appeared on the market.

"How much money and labour were spent before they realized their mistake?" someone may say. "It's a good thing that the water at least proved salubrious."

But strange as it seems, the "mistake" made the geologists happy. They began to spend even more money on drilling holes near the "Shaambary" resort and went on doing so until a powerful fountain of blue fuel gushed up and a new major gas and oil deposit was marked on the map of Tadjikistan.

So the "mistake" confirmed, but by no means refuted the geologists' predictions.

Gas, oil, and ground waters may be neighbours, as it were, living on different floors of the same porous-reservoir house. The heaviest of them, water, prefers the ground floor. This



Petroleum in the clutches of edge-water and inside flooding.

is well known to geologists and if they break into one flat instead of another they are only too glad. For they know that the neighbours they are looking for are sure to be somewhere nearby.

And now imagine the water family growing. It soon becomes cramped for space on the ground floor, and begins to force the gas and oil upwards. Now if a well is drilled to give them an exit, the gas and oil will come out of it of their own accord.

That is why water is pumped into underground formations. It rings in the petroleum and gas, driving them upwards. This method of extraction has long been known as edge water flooding.

But in the fifties of this century a fantastically large oil field with the poetic name Romashkino* was discovered in Bashkiria. The

* *Romashka* is the Russian for daisy—*Tr.*

only trouble was that the black gold was very difficult to bring to the surface. It would have taken a hundred years to pump enough water into it to make the oil feel cramped for space. Then was born the daring idea of setting up two concentric water rings instead of one. When this method was applied the oil started flowing. Thus, inside flooding proved a valuable supplement to edge water flooding.

Good. But some reservoirs yield their petroleum if water is pumped in at a pressure of 70 or 75 atmospheres, while others are denser and require a pressure twice as high. Otherwise half of the wealth remains where it is.

In recent years this problem has also found a solution. Water is pumped into different reservoirs at different pressures. But here instead of a friend water sometimes becomes an enemy From the dense oil-bearing strata it breaks through into the weaker ones, and the reservoirs have to be sealed up with cement, burying unextracted supplies of "black gold".

The Earth has set men a very complex crossword puzzle. Now ways have to be found of isolating artificially flooded oil-bearing strata from one another.

The squares of this crossword puzzle contain the words: "Gas", "Petroleum", "Reservoir", "Pressure", and the most important of them, "Water". On the last named largely depends how much of this remarkable gift of nature will be extracted and how much will remain buried underground forever.

Incidentally this water we all know so well has brought up other crossword puzzles.

Visit a building site some fine day, and you will see heaps of sand, stones, and perhaps an area of hardened clay. Now imagine yourself suddenly swimming in such hard clay.

Do you find it difficult to imagine?

Then here is a true story to help you.

One fine afternoon a herd of cows, sheep, and goats was dispersed over a large green meadow, placidly nibbling the grass. Soon it was time to go home, and the shepherd played a tune on his flute. The animals started up, gathered together at one spot and were just going to start off for the village when suddenly... they were all floundering about in a lake. By the time the peasants had run up, thought of what to do, and started doing it, the major part of the herd was drowned.

This happened in Norway, where such occurrences are not infrequent.

But what had happened? Why did the clay underneath the soil cover of the green meadow suddenly become liquid?

Nobody could account for it, until experts in engineering geology undertook to solve the riddle of this "miracle". They sampled the ground, performed hundreds of experiments, and thoroughly studied the geological history of the district.

Their findings were that many thousands of years ago there had been an ancient sea in those parts. Minute particles of soil washed off the seashore and from the banks of the rivers and rivulets that fell into the sea, settled to the bottom of its deep and unperturbed zones. In the course of many years they had formed huge layers. The salt dissolved in the sea water had cemented these particles into an integral whole, transforming them into marine clay.

Now let us return to the building site. You see the workers mixing gravel or broken stone, known as aggregate, cement and water to make an artificial stone—concrete. Cement is a building glue, as it were, with which the sections of large dams or loose sand particles can be held together.

Our marine clay also consists essentially of an aggregate—minute soil particles, and a cement—salts and water. When the sea receded and its bottom became dry land, the clay fell into a different environment, that of flowing fresh water. Such water readily dissolves the salt it encounters on its way through the ground and carries it away to its runoff point. Thus, in the course of thousands of years fresh water washed the salt cement out of the marine clay. And then there came a time when a fairly strong vibration was enough to make it flow, to turn it into a little lake of water and fine soil particles. Such was the explanation of the "miracle".

Why does Mud Form?

As to the minute soil particles everything is quite clear. They formed as a result of the prolonged destruction of rocks. But why can clay contain so much water? The reason is just because it contains these minute particles. The more there are of them in the soil, the more moisture it can absorb. Stones and sand can hardly hold any on their surface. After a heavy shower on a sandy or gravel road is over it is as if there had been none: the road is quite dry and passable.

A clay road is an entirely different proposition. As long as it is dry, the road is quite good. But only a little rain puts it entirely out of commission. Vehicles skid on it, and on your way to work, you are more likely than not to lose your rubbers and get very dirty.

"What awful mud!" you think angrily.

"Why is it so slippery and sticky?" Here is why.

Instead of sinking through into the ground or draining into a depression, almost all the rain that fell on the road remains on it. Under the action of molecular forces of attraction each clay particle surrounds itself with a film of water. It amounts to about the same as smearing bicycle ball bearings with a layer of oil. Then they slide well and adhere to one another. But to separate them you have to exert a force capable of overcoming the cohesion between the ball surface and the oil. No wonder an inert backward person is called a "stick-in-the-mud", meaning he is incapable of overcoming the force of inertia that prevents him from keeping up with his fellows.

Finally, you may ask: "Then why does mud dry if its particles hold on to their moisture so strongly?"

This is because in time the water evaporates from the upper layer of the road. But down below... dig down once or twice with a shovel and moist clay is sure to stick to it. Down below it is always damp.

In this case the word speaks for itself. To drop means to fall downwards. But can a drop drop upwards? "No," say you. "It cannot. That would be contradicting the laws of physics."

"Yes."

"But what if, apart from gravity, we take molecular attraction into account? Then we get the opposite answer."

Thus, both "yes" and "no" are correct.

Rub a piece of soil between your fingers and observe it through a magnifying glass. You will see that the particles it is made up of have a variety of shapes. That is why no matter how you compress them, there will always be spaces left between them called pores. The smaller the particles, the smaller will be the spaces between them. Usually many of the pores are filled with moisture. This is most often the water which has trickled down from above, for instance, rain water.

You know that very fine particles are capable of retaining a thin film of liquid on their surface. Besides, they are frequently also surrounded by weakly bound, or even unbound, water filling the pores freely. Under certain conditions this free water behaves too "freely" indeed.

When the first frosts come in winter, the cold penetrates slowly into the ground. In the upper layer of the soil the thickness of the liquid films decreases sharply. Here most of the water has already frozen. But lower down, where the breath of winter has not yet penetrated, its quantity remains as before. Now the wonderful mechanism of molecular attraction begins to operate. The particles in the top layer of the ground try to surround themselves with a new liquid film to replace that removed by the frost. To help them moisture from down below is drawn as if by a magnet through the overlying pores, and immediately turns to ice. More and more droplets come up to take its place, but all of them are immediately frozen by the treacherous cold.

The net result is that whole layers of ice may form in the top zone, making the soil give way. But the soil can give way only upwards, and the earth "draws in its breath"—the ground begins to heave. See how much strength there is in a tiny drop of water! It pushes out great posts as if they were matchsticks, lifts buildings, and splinters the trunks of century-old trees.

When warm weather comes the ice melts. The "free" water partly evaporates and partly seeps down into the interior, leaving empty space. The ground, especially if it is slimy and clayey, settles under its own weight or under the load it bears, "exhaling", as it were. This is the reverse process, that of shrinkage. Now again one has to be very careful: a building may go askew, its walls may crack and it will be demolished.

IS IT SOLID GROUND WE TREAD ON?

The Secret of the Tower of Pisa

What is the connection between construction and geological prospecting?

At first glance this seems an appropriate question, but actually it is based on ignorance. Prospectors look for economic minerals—petroleum, coal, ores, and many others. Then people need water too. But finding them is not all. Coal, for instance, can be converted into heat, electricity, plastics, etc., only if coal mines, power stations, and processing plants are built. To make water serve mankind dams and pumping stations have to be erected. And they must be erected to last for years and years. To do this one has to have a knowledge of engineering geology, and be versed in such sciences as soil science.

"Oh," you will say, "knowledge, my eye! It's all very simple. Wherever you raise a structure it will stay put. Unless, of course, there is an earthquake or some other calamity."

But is this really so? The leaning tower of Pisa in Italy has become a place of pilgrimage for thousands of tourists each year. Some of them are probably enraptured by the skill of the builders who were able to build this tower inclined. And it is very likely a shock to them to find out that it was built upright, as towers should.

It was the builders' ignorance of the properties of the soil under its foundation that made it famous. And now, for eight centuries already the soil is slowly subsiding and creeping. Each year the leaning tower slants more and more and if not supported it will collapse sooner or later.

The Soviet Union also has its "towers of Pisa". For example, there is the twenty-metre Vladimir Tower of the Novgorod Kremlin on the banks of the Volkhov. At one time a small chapel was built at its northeast wall, and it started to drag the tower down the slope of the hill on which the Kremlin stands.

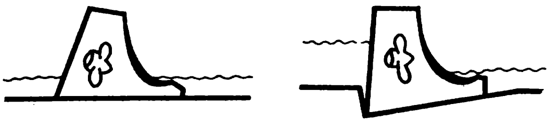
Builders took down the chapel and put a new foundation under the tower. Now only a bend in its outer wall reminds us that the Novgorod beauty had been under the same threat as its Italian sister. Thus, what seems unquestionable to us may be a treacherous puzzle to builders, especially if the bases their buildings stand on consist of various layers: clayey, peaty, sandy, and other soils.

As a rule, some of them are more, others less compact, and their water saturation differs. The layers may also vary sharply in thickness. All this may result in dangerous nonuniform settling and destructive shifts.

That is why investigators need so much knowledge and even daring ideas.

A Crime? No, a Service!

The finishing touches are being made in the foundation area in front of the dam of a hydropower station. Soon enormous masses of water will fill it. Turbines are already installed in the spacious engine room. But they stand inclined!



The turbine, installed at a slant at first, is aligned correctly after settling.

"It's an outrage," you will say. "Is not the historical example of the tower of Pisa sufficient? Moreover, in an inclined turbine the friction parts will wear unevenly and lubrication will be faulty! It's headed right for an accident."

But years later the turbines still operate normally, and, what is more, they are now upright. What is this? Has anyone righted the incorrectly installed machines?

But geological engineers, experts on foundations and bases, would explain quite matter-of-factly: "It is all because of the large number of tests carried out with soils and hence correct prediction of all subsequent phenomena." Yes, correct prediction! We shall not dwell on the effort it took. Better look at the drawings.

Which Is Better, to Improve or to Worsen?

"To improve, of course," you will answer. "People are always striving to make everything better. Can this be put to doubt?" Strange as it seems, it can.

In a certain city a decision was passed to erect a large building, and the ground at the site was accordingly investigated to a considerable depth.

It was found that just below the soil was a layer of clay, and then rocky ground. On one side of the future foundation it came close to the surface, but on the other side it struck downwards.

Geological engineers made calculations to find how the clay would settle under the weight of the structure. They showed that where the rocky ground was deep down, part of the building would settle a few score centimetres, but where it came close to the surface there would hardly be any settlement at all. This meant that the building might easily break down.

What was to be done? Improving the base to decrease settlement as much as possible would involve removal of an enormous amount of clay, which would have to be replaced by some other soil. This would be difficult and expensive.

Then it was decided to do the opposite, that is, to make the base worse. Where hardly any settlement was expected, a little earth was removed. Then the ground was ploughed deep so that after the house was built the loosened clay would give the greater extent of settlement needed.

The construction job was finished long ago, but the immense building still stands firm in full view of the noisy city.

As you see, making things worse made things better.

Piles Can be Filled In

Piles have been used by builders since ancient times for reinforcing bases. Usually wooden piles are used, sometimes metal ones. They are driven into the weak ground until they reach a compact layer. The structure is erected on the piles and now it stands on a solid base.

The famous St. Isaac cathedral in Leningrad also stands on many thousands of such piles. But they are not eternal. Wood rots and breaks down with time. For this reason a special state commission had to be set up recently to study the question of preserving the grandiose, practically eternal historical monument built on such a non-eternal base.

But is it possible to make piles capable of existing as long as the stone buildings placed on them?

It appears that it is. "Probably using a very hard and expensive material?" you assume.

No! Using ordinary river sand to fill in holes drilled, say, with a vibrodrill. After this the sand is compacted. Such sand piles are not only a splendid base for building, but also excellent drainage wells for removing water from weak grounds.

And water is the enemy whose presence almost always deteriorates or changes the construction qualities of the ground. A clever type of filled-in piles is also used in China. There the holes are filled with quicklime, which is then compacted. When the lime is slaked, a chemical reaction takes place in the ground. The lime removes water from the surrounding areas and increases its volume.

This is "killing two birds with one stone": the ground is dried and compacted at the same time.

It Was No Accident

We are in a seaside town.

How strong and beautiful is this granite embankment built back in the last century. Only there are little depressions in the pavement. What made them?

Maybe they are due to damaged water mains and the heavy showers that fell at the end of

September. Following up this idea the pavement was pulled up and the water main repaired. Then the ditches were filled and the pavement replaced. They thought that would do the trick.

But a month later a section of the embankment 300 metres long came to life. It started shifting seawards at the rate of a quarter of a metre per day. In a few days it was disfigured by great gaps. The strong granite wall broke into pieces and fell into the sea.

A commission set up for the purpose could not find the cause of the catastrophe. Then the question was rightly handed over to geological engineers, who found that a few months before the embankment had crashed the sea bottom at the wharves in the port had been deepened and the dredger had removed earth according to the principle: "dig as deep as possible." It had dug down so much that the embankment began, imperceptibly at first, but then faster and faster, to slide into the sea. The shores in those parts are clay, and there is no need to explain again that moist clay is plastic and apt to creep, and sometimes even flow.

Thus, the law of equilibrium had been violated and the result was a shift of the earth massif down the slope. The damages amounted to millions of rubles. This need not have happened.

A Chimney and a Well

In the south, at one of the largest iron and steel plants, a tall brick chimney was erected. After some time it began to lean over and was about to collapse. An urgent "consilium" of foundation experts was called, who declared: “Some water reservoir is responsible. It must be somewhere nearby, in the direction of maximum inclination of the stack.” The suspected area was investigated, and indeed, a temporary well was found, which the builders had used for draining water.

You may object: “What has water-collecting wells to do with it? They are almost always made next to large structures and nothing ever happens.” But many wells have special outlets made of metal or concrete pipes, but this one had none.

Besides, grounds may be not only sandy or clayey. So-called loess deposits are widespread in the south of the Soviet Union. While other grounds swell when they get wet, loess grounds subside, on the contrary. Water breaks down the rigid skeleton between the soil particles, so that they are compacted and take up less space.

That is why some canals and rivers in the south have banks resembling the steps of a gently sloping staircase. They were made by water moistening the loess ground to different degrees. That is approximately what happened under the foundations of the chimney stack.

Of course, establishing the cause was only part of the job. It had yet to be eliminated. Calculations were made and several alternatives were suggested. And, as it often happens, the simplest solution turned out to be the wisest. A load of several hundred tons was placed on the side of the stack opposite to its inclination, and it balanced the subsided part of the foundation, like on a pair of scales. And the stack not only stopped falling but even gradually straightened out.

How a Tower "Grew up"

Even dry land is known to contain water. How much? Some grounds contain little of it, but others...

In one of the northwest regions of the USSR an ordinary water tower was erected. Since the ground at the base was weak, long piles were first driven into it to add strength. On them a foundation was built, and on the foundation, the structure. When the tower was finished, the motors were switched on and water began to run through pipes from a small lake to the settlement. After some time a few steps had to be added to the entrance, as the building had grown slightly. Then it began to grow faster, and finally a high staircase had to be put up to make the tower accessible.

What is the reason for this "miracle"? The only possible answer lies in the base of the structure. Peat grounds, on which the tower was erected, are remarkable for the fact that even in a relatively dry state they contain a "sea" of water and only an "island" of dry land.

The liquid itself hardly contracts. But if it is removed, say, drained away, in some direction, numerous cavities appear. Then the peat ground becomes compacted, and may subside several metres.

In pumping water from the small lake nearby, the water tower practically sucked it out from under itself. This made its piles—those which had previously been driven deep into the ground—"grow into long legs".

The above examples are eloquent, aren't they? But if you have been attentive, you will have noticed that we have been speaking of the use of engineering geology only on half the territory of the Soviet Union, the half where there is no permafrost.

But an extensive construction programme is also underway in the northern and eastern parts of the country, which are rich in natural resources. In the severe climate of these territories everything must be different, and more complex.

"In Yakutsk Province, Your Majesty ..."

"In Yakutsk Province, Your Majesty, according to the tales of merchants and manufacturers, there is no hope of cultivating corn. The land, they say, Your Majesty, does not thaw even in summer." So ran a report sent to Moscow more than three hundred years ago by the Lena governors P. Golovin and M. Glebov.

At that time the inhabitants of that distant city lacked not only cornfields, but even water. To get drinking water they had to travel in winter to the Lena River and cut out huge lumps of blue ice.

Later, in 1685, another governor, Matvei Krovkov, tried to penetrate into the ground of the Yakutsk Province. And he was also obliged to report: "And wells, Your Gracious Majesty, cannot be made in Yakutsk by any means because the earth thaws in summer only to a depth of one and a half arshins, and cannot be penetrated deeper than two arshins, the bottom of the hole always being frozen ground..."

But human nature is stubborn. A little over a hundred years passed and F. Shergin, a civil servant, decided "to go against the grain", i.e. to find water in the dis rict, despite everything the old-timers told him, by digging a "Russian"-type well. The crew started it in 1812 and dug for ten years. But at a depth of 116.4 metres they gave it up. There was no water, only frozen ground. "Is there no end to it? Where does it come?!" asked the stubborn man in despair. Nobody could supply the answers to these questions, and he died without having found them.

But "Shergin's well" remained. Later it was used for the first investigations of permafrost ground.

This ground possesses extraordinary properties. It is strong as stone and impermeable to water, making it an excellent base for heavy buildings and mines. Designers even decided to make the core of one of the dams of frozen ground, rather than concrete.

It is precisely frozen ground that makes it possible to cultivate plants and vegetables in the north. It retains moisture in the upper layers of the soil even during the hot days of summer. Without frozen ground continental Yakutia would become a desert.

But at the same time frozen ground is an enemy. There is a project for heating the northern and northeastern districts of the Soviet Union, which suits everybody except geocryologists, the geologists who study permafrost. They know that the ice layers supporting the ground will then melt and the frozen sandstones and loams will become many-kilometre-wide impassable expanses of water and mud.

Frozen ground may push piles out of the soil, demolish houses and other structures. The hill next to the building of the Yakutsk Institute of Geocryology was also pushed upwards out of the earth by gigantic forces. Those who work at this Institute do not have to travel far to find facts. They are right there. Still, they are quite mysterious.

Is it not remarkable that liquid water can be found in frozen grounds even at minus 20°C?

It seemed an infallible truth that to build even one-storey houses in the north is dangerous owing to congelation (frozen ground) phenomena But the investigations of scientists showed that frozen foundations could easily bear loads 2-2.5 times greater than ordinary ones, and storeys began to be added to the houses in Yakutsk.

Not many of our readers have probably ever been in a laboratory where the floor, ceiling and walls gleam, both winter and summer, like in a fairy tale, with grains of ice. The Institute has such a laboratory 15 metres below the surface of the ground. In it and in other scientific institutions of the country many "permafrost" problems are solved. And the most important of them is the following.

Is "Permafrost" Permanent?

A strange question. The very word "permafrost" supplies the answer. But unfortunately this is one of the fallacies of science where an original name is retained in spite of modern knowledge. Actually, permafrost is not permanent.

It appeared only a few tens of thousands of years ago. At that time, ancient glaciers covered the north and east of the country that is now the USSR. Like a gigantic refrigerator they froze the ground through and through, sometimes to a depth of many hundreds of metres. Then it became warmer. The glaciers retreated to the Arctic Ocean. Perhaps, what are known as vanishing islands, which have more than once excited the imagination of Polar travellers, are actually the remains of these glaciers. The secret is that these islands, which are really icebergs disguised on top with a layer of earth, just melt.

Several decades ago even the founders of geocryology considered permafrost to be a product of climate and a heritage of the Ice Age. Hence all problems were attacked in the same way.

Buildings were started on permafrost in Vorkuta and the Pechora coal basin. But very soon an alarming thing happened. In 5 or 6 years the so-called permafrost stopped being permanent. At first particular reasons were sought. But then it became clear that in this region the equilibrium in the natural interchange of moisture and heat had been disturbed unknowingly by men. Thus, there is nothing more changeable than northern frozen ground, especially if it consists of dust and clay.

About 45 per cent of the territory of the USSR is in the zone of frozen rocks. In the north they lie as a continuous ice sheet, further south they form islands. Their thickness has been studied thoroughly, and also found to be variable. At a point 450 kilometres north of Mirny, the diamond capital, this zone extends 1,500 metres down into the earth's crust. But at the same latitude near Verkhoyansk the thickness of permafrost is only 250 metres, and at another point, only 70 metres. This is still a riddle.

Geocryologists have started out to solve it and have found that the reason lies in natural brines which penetrate the cracks in the rocks. They probably create cold zones, which actively remove intraterrestrial heat.

In the north of western Siberia the permafrost layer is also very thick. In Yakutsk it extends down to a depth of 250 metres. That is why Shergin could never have reached thawed ground even if he had kept digging his well all his life. But at that time nobody could explain this to him.

What Is an Active Layer?

You know already that frozen ground is hard as stone. But there is a "but". Even in the north and east of the USSR the earth thaws to a depth of a few score centimetres in the course of one summer season. More in some places, less in others. The result is a kind of cake with a layer of strong frozen ground underneath and a thin layer of thawed ground on top. Thawing makes the ground moist, and sometimes even fluid. It subsides and begins to creep. Each step you take over the ground in early spring reminds you of this.

In winter the ground is frozen again. To be more exact, it is the water in it that is frozen.

So much of it may accumulate in the ground that often a small ice filling forms and this makes the surface layer swell, for which reason this layer is called active. A house resting on such ground will rise and fall as if on the waves of a rough sea, and will finally fall to pieces.

You may think that the whole trouble lies in the active layer. If this were so, it would be sufficient to remove it and set the building on the non-thawing frozen ground. To put it more simply, it would be necessary only to dig an ordinary pit under the foundations, as is done in the middle zone or in the south of the country. That is just how houses were built at first in the "permafrost" zone. And the results were always the same: the houses very soon toppled down.

Then scientists tackled the problem, and they soon found the main enemy. A house would be built on frozen ground. At first everything would be all right. People would move in and start to live there, and of course heat it. And the house would heat the ground. This would form a thaw basin under its base, which means that the foundation was again in the zone of action of the active layer. Hence, cracks, skewing, and finally breakdown.

Thus, the main cause is disturbance of natural heat exchange. But heat is also man's best friend. A person living in the north will never make his home in a house without it. Therefore an intermediary had to be found, which could reconcile ice and fire—the source of heat.

It sometimes happens that suddenly water begins to seep up into a house in winter. The people move out, and after some time the house becomes an ice house. Ice begins to creep out of its windows in long tongues.

What has happened? The point is that ground waters not infrequently flow under the seasonally freezing and thawing layer of soil. They cannot seep downwards through the "permafrost", and so in winter they are sandwiched in between the crusts of frozen ground above and the congelated rocks below. The frost grows stronger, the crust grows thicker and it squeezes the ground waters out wherever the active layer has not yet frozen or does not freeze at all. Thus, layers of ice form following the line of least resistance, both in open spaces and in built-in districts.

Ice layers are formed by cold. And they were conquered by cold. To do this trenches are dug in summer in the active layer around the structures. When the frost comes the trench walls freeze quickly right down to the permafrost layer and form a strong fence, which does not allow the ground waters to pass through and can withstand any pressure. Hence, in clever hands, even cold is a helper. Perhaps it will help to overcome unstable foundations? Then permafrost should be left at the base of structures.

On Stilts

Air is an excellent heat insulator and cooler, and we have plenty of it all around us.

"Wait!" we hear objections. "You can't erect a building on an air filling. Houses are built by men, not magicians!"

Well, if you want to know, most structures of such cities as Norilsk, Yakutsk, and Vorkuta are actually built on "air fillings", and they are very strong and reliable.

The method of retaining permafrost as the base for buildings by using a layer of air for heat insulation has become known in practice as the "ventilated or cooled basement method". To make this basement the house is simply raised 0.5 to 1 metre above the ground. It is set on "stilts", or a post foundation in engineering terms. Such foundations are made mainly of reinforced concrete. They were first built in Norilsk, and now each year about ten thousand foundations of this type are driven into the ground of this city. The piles can be made quickly and cheaply at special plants. But there is another obstacle. It is difficult to drill holes for them in the permafrost which itself is as hard as concrete. And here again heat comes to the rescue. It takes a thermal drilling unit only half an hour to burn a hole in the ground. Here even the exhaust gases are of use, since they carry the crushed rock, dust and steam from the conquered ice out on to the surface.

You know, of course, that in northern cities hot water and steam heating are provided in all houses. This is not only for the comfort of the inhabitants. The hot water pipes protect the water mains and the drainage system from freezing. All these pipes are now laid together in special conduits. And as long as the steam is running no cold can freeze or damage the pipes.

To keep the "underground" heat from injuring the structure, the pipes are laid at some distance from them, say, down the middle of the street. The branches leading to the buildings come out on to the surface and pass into the house along posts, leaving an air layer below for heat insulation.

Hundreds of cities and villages are growing in the north and east of the Soviet Union. And many of them are situated on permafrost, and are there to stay for hundreds of years, though they stand on "stilts".

FACTS FOR THOUGHT

The trouble caused different reactions.

"What the hell..." swore the drillers. The drill would break, as a rule, at a depth of 150 to 400 metres.

"It's fantastic," shrugged the experts. "Every hundred metres the temperature should increase by 2.5 to 3°C, but it does just the opposite."

"Well, that's strange," said the designers, as if apologizing. "There is very little wax in Tyumen oil, and so we were positive no special methods of cleaning pipes and equipment had to be provided."

The cause of these surprises was found in western Siberia much farther south than scientists had anticipated.

This again gave rise to speculation. Maybe make use of the experience of Norilsk builders? Leave the treacherous permafrost alone and provide heat insulation by means of an air layer between the walls of pipes of different diameters? This would be more expensive, but would defeat the water, that two-faced Janus...

How many questions the discovery of underground permafrost layers brought up! But could the invisible have been foreseen? The more so, in a pioneering territory? It is a different matter with the well explored regions of the country. For instance, who would ever expect to discover anything new in the central regions under the birch groves and apple orchards? Still, it was here that an immense sea 700,000 square kilometres was found, with its centre at Talalikhin Street, Moscow. The waters of this invisible sea can be used as a curative, for heating and refrigerating, and as a source of valuable salts.

Farther south is another invisible phenomenon. The underground Voronezh range. It contains the tremendous reserves of iron of the Kursk Magnetic Anomaly. The rocks of this range are similar to those in which nonferrous and rare metals so much needed by industry are often found. Kimberlite has also been detected here, and hence there may be diamonds.

The iron quartzites of the Kursk Anomaly were formed hundreds of millions of years ago in ancient Precambrian water basins. During that distant epoch 3.4 trillion tons of such minerals accumulated on the Earth, whereas during all the time since then only 135 thousand million tons accumulated. Why? That is something worth thinking about.

We investigate dry land very thoroughly, using the most perfect prospecting methods. But so far we have been studying the interior under the seas and oceans very timidly. There, on the floor, lie hundreds of thousand millions of tons of spherical stones consisting of iron and manganese. There are also copper, nickel, cobalt, and other valuable metals there.

Water itself is virtually a liquid ore. If all the chemical elements needed by man were collected from it, they would cover all the dry land on Earth with a layer 200 metres thick. It is no doubt worth while pondering over such calculations.

At first glance it seemed an accident. Once a waggon of geologists was travelling over the steppe, and got stuck in a ditch. To drag it out they used a log as a lever, with a stone as its fulcrum. Then they looked at the stone and found a mountain crystal in it. Now who would ever have thought they would find such a crystal at that place, where there were no mountains to be seen? Whoever would have thought that that place would become the site of the world's largest piezocrystal mine? However, this is also a fact that helps to understand the regularities of distribution of nature's invisible wealth.

To many scientists it is a truth requiring no proof that oil and gas formed from the remains of ancient animals and plants. "Black gold" and "blue fuel" should therefore be sought among sedimentary strata. But on the Kola Peninsula both surface and deep-seated rocks are magnetic granites and basalts. Still it was here that a foreman of an appatite mine located near the city of Kirovsk once heard a strange whistling sound coming from the dark interior. He struck a match and there was an explosion. Fortunately, the men were not seriously injured, but great damage was sustained by the theory of the organic origin of petroleum. Scientists established that there may be gas deposits among the magmatic rocks in the vicinity of Kirovsk. Is this an accident or is it the forerunner of an important discovery?

Facts for thought. What a multitude of them: general and particular, regular and unexpected, often refuting accepted hypotheses. And there are so far very few of these. Geology has had no Charles Darwins or Dmitry Mendeleyevs to systematize and generalize all the regularities of formation and distribution of underground treasures, and probably never will.

The science of the Earth is an ocean of sciences. To master it is the task of thousands of contemporary and future researchers.

* * *

And so, there is still so much to be explained. And that is why we have called our familiar Earth a planet of riddles.

You have read of only a few of its mysteries here, but how many more of them still have to be solved! That is why we must embrace the boundless—unlock the secrets of the Universe, and see the invisible—find the key to the treasures of the interior that lie underfoot.

Where? How? Why? are the favourite questions of scientists. They find the answers and these answers become historical facts, giving rise to new questions. Such, essentially, is the path of development of knowledge.

Printed in the Union of Soviet Socialist Republics

ABOUT THE BOOK

This book is about our planet, the Earth we know so well. But is it then a planet of riddles? Read this book, and you will see that it is.

Whence the strange names of the sections: "Embracing the Boundless", "Seeing the Invisible"? Has the author forgotten Kozma Prutkov's aphorism: "You can't embrace the boundless"? Not at all! But he does not agree.

The book gives a brief history of the study of our planet. But history contains the roots of scientific novelty, of wonderful discoveries. Kozma Prutkov also said, and not without reason: "Heed the roots!"

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